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NAVAL POSTGRADUATE SCHOOL

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INVESTIGATION OF THE POTENTIAL MATERIAL SOLUTION FOR UTILIZING AN UNMANNED AERIAL SYSTEM TO PROTECT OFF-SHORE OIL PLATFORMS FROM SURFACE THREATS

by

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14. ABSTRACT
This paper describes a potential material solution for the utilization of an unmanned aerial system to identify, discriminate, and engage potential surface threats to off-shore oil platforms. The intent of the research effort was to identify how US maritime forces are presently deployed to protect off-shore oil platforms from sabotage, takeover, or destruction and to determine if an unmanned aerial system could be utilized to enhance that effort and perhaps reduce the manpower requirements. While numerous possible threats exist including aerial and sub-surface attack, the present study concentrated on surface threats.
A disciplined systems engineering approach was utilized to determine the most cost-effective solution that meets key stakeholder requirements for identifying, engaging, and neutralizing potential threats in a time-critical manner through either lethal or non-lethal means. The initial capability requirements are decomposed into functions to be performed and the functions are evaluated through consideration of either fixed-wing, rotary-wing, or lighter-than-air platforms using standard systems engineering tools and methods to determine the most cost-effective solution that meets stakeholders needs. Architectural views and functional block diagrams are provided which meet stakeholder requirements and a preferred solution is provided along with recommendations for further research.

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This paper describes a potential material solution for the utilization of an unmanned aerial system to identify, discriminate, and engage potential surface threats to off-shore oil platforms. The intent of the research effort was to identify how US maritime forces are presently deployed to protect off-shore oil platforms from sabotage, takeover, or destruction and to determine if an unmanned aerial system could be utilized to enhance that effort and perhaps reduce the manpower requirements. While numerous possible threats exist including aerial and sub-surface attack, the present study concentrated on surface threats.

A disciplined systems engineering approach was utilized to determine the most cost-effective solution that meets key stakeholder requirements for identifying, engaging, and neutralizing potential threats in a time-critical manner through either lethal or non-lethal means. The initial capability requirements are decomposed into functions to be performed and the functions are evaluated through consideration of either fixed-wing, rotary-wing, or lighter-than-air platforms using standard systems engineering tools and methods to determine the most cost-effective solution that meets stakeholders needs. Architectural views and functional block diagrams are provided which meet stakeholder requirements and a preferred solution is provided along with recommendations for further research.

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EXECUTIVE SUMMARY

Global terrorist threats targeted at oil production and distribution facilities are a clear and present danger. The United States along with the global economy depends on the secure use of the world's oceans, including mining of resources and their safe transportation to market. As evident in the 2010 oil platform disaster in the Gulf of Mexico caused by accident, a deliberate attack by a determined enemy can cause significant environmental and economic damage to the United States or its allies and the global economy. Therefore, an urgent need is required for the capability to provide continuous, all-weather, autonomous protection of domestic and foreign oil platforms to ensure against an attack which could cause similar calamity.

This project was initiated to investigate a potential technological material solution to counter present and future threats to the US national or global oil production and distribution infrastructure which has been identified as a prime terrorist target. Due to the documented threats to the oil platform infrastructure, the Variable-mode Unmanned Long-range Tracking Unit for Reconnaissance & Elimination (VULTURE) team was formed to develop an affordable technology based solution to protect and defend off-shore oil platforms. This research team includes select members of the second cohort of the Master of Science in Systems Engineering (MSSE) program offered by the Naval Postgraduate School (NPS) in conjunction with the Naval Air Systems Command (NAVAIR).

The VULTURE team conducted several mission scenarios and considered many possible engagement strategies and responses. Originally these responses included airborne, surface, and sub-surface threats to both domestic and foreign oil platforms. The resultant solution space quickly became too unwieldy and unrealistic to be considered in the time frame and within the constraints and the desires of the MSSE program. Therefore, the VULTURE team prioritized the threats, engaged stakeholders to determine their immediate needs and wants, and focused on how to identify, track, and neutralize surface threats to the oil platforms in waters outside the continental US by use of an unmanned aerial system. The determination of specific type of air platform, its technical performance, payload capability, and cost consideration are the subjects of this report.

This paper describes a potential material solution for the utilization of an unmanned aerial system to identify, discriminate, and engage potential surface threats to off-shore oil platforms. The intent of the research effort was to identify how US maritime forces are presently deployed to protect off-shore oil platforms from sabotage, takeover, or destruction and to determine if an unmanned aerial system could be utilized to enhance that effort and perhaps reduce the manpower requirements. While numerous possible threats exist including aerial and sub-surface attack, the present study concentrated on surface threats.

A disciplined systems engineering approach was developed and utilized to determine the most cost-effective solution that meets key stakeholder requirements for identifying, engaging, and neutralizing potential threats in a time-critical manner through either lethal or non-lethal means. As detailed in the report, our systems engineering methodology included the steps of: define the problem, develop a concept of operations, develop the requirements, identify a concept of alternatives, and through analysis develop a solution system architecture that could potentially address the problem. With feedback from the stakeholder, this analysis is substantiated as a potential solution to the problem. The initial capability requirements were decomposed into functions to be performed and the functions were evaluated through consideration of unmanned aerial systems consisting of either fixed-wing, rotary-wing, or lighter-than-air platforms using standard systems engineering tools and methods to determine the most cost-effective solution that meets stakeholders needs. Architectural views and functional block diagrams are provided which meet stakeholder requirements and a preferred solution is provided along with recommendations for further research. We concluded that a rotary-wing unmanned aerial system would be the best overall performer to accomplish the specific mission of oil platform defense.

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I. INTRODUCTION

A. BACKGROUND

As detailed in the *National Strategy for Maritime Security* "The safety and economic security of the United States (US) depends upon the secure use of the world's oceans [1]." Further explanation from that document cite that "the President directed Secretaries of Defense and Homeland Security to lead the Federal effort to develop a comprehensive National Strategy for Maritime Security…[1]" Furthermore the US Department of Defense (DoD) and the Department of Homeland Security (DHS) as directed by Homeland Security Presidential Directive 7: Critical Infrastructure Identification, Prioritization, and Protection, are directed to "identify and prioritize United States critical infrastructure and key resources and to protect them from terrorist attacks [2]." This Presidential directive instructs the federal departments and agencies to "work with foreign countries and international organizations to strengthen the protection of United States critical infrastructure and key resources [2]." As a consequence of those requirements, US maritime forces are presently engaged in the defense of off-shore oil platforms in the Persian Gulf and other waters. It is a labor-intensive effort requiring the capability to identify and quickly discriminate any approaching vessel to determine if their intent is to do harm or merely passing by.

This project was initiated to investigate a potential technological material solution to counter present and future threats to the US national or global oil production and distribution infrastructure which has been identified as a prime terrorist target. Oil Platforms (OPLAT) fall under the 'energy sector' as identified under the "Critical Infrastructures Protection Act of 2001 [3]". Therefore, based on the core maritime power projection goals [1] and the documented threats to the OPLAT infrastructure, the Variable-mode Unmanned Long-range Tracking Unit for Reconnaissance & Elimination (VULTURE) team was formed to develop an affordable technology based solution to protect and defend off-shore based OPLATs. This research team includes select members of the second cohort of the Master of Science in Systems Engineering (MSSE)

program offered by the Naval Postgraduate School (NPS) in conjunction with the Naval Air Systems Command (NAVAIR).

The VULTURE team conducted several mission scenarios and considered many possible engagement strategies and responses including airborne, surface, and sub-surface threats to both domestic and foreign OPLATs. The resultant solution space quickly became too unwieldy and unrealistic to be considered in the time frame and within the constraints and the desires of the MSSE program. Therefore, the VULTURE team prioritized the threats, engaged numerous stakeholders to determine their immediate needs and wants, and focused on how to identify, track, and neutralize surface threats to OPLATs in waters outside the continental US (OCONUS) by use of an Unmanned Aerial System (UAS). The determination of specific type of air platform, its technical performance, payload capability, and cost consideration are the subjects of this report.

The common Command, Control, and Communication (C^3) ground station system which could be utilized by the VULTURE air vehicle was the subject of the first NAVAIR cohort and each variant of the proposed VULTURE air vehicle is planned to be fully compliant with their recommended architecture. The initial maritime Electrical/Optical and Infrared (EO/IR) payloads which could be employed by each variant of a VULTURE air vehicle have also previously been researched by NAVAIR and will be discussed in later sections of the report.

B. OBJECTIVE AND RESEARCH QUESTIONS

1. Project intention

Threats to oil production and distribution facilities are a clear and present danger. As evident in the 2010 Oil Spill disaster (Figure 1 from [4]) in the Gulf of Mexico caused by an accident, a deliberate attack by a determined enemy can cause significant environmental and economic damage to the US or its allies and the global economy.

Figure 1: Gulf of Mexico 2010 Oil Spill

Therefore, the capability to provide a continuous, all-weather protection of domestic and foreign OPLATs is required to ensure the safe and reliable provision of petroleum to consumers. The employment of a UAS to accomplish that mission seems to be a practicable approach, and is an important objective of this research.

2. Areas of research to investigate

What functions, subsystems, and components are required for the VULTURE system to achieve the ability to detect, engage and neutralize surface threats in a time-critical environment and allow for successful defense of OPLATs?

What Measures of Effectiveness (MOE) should be used to determine the value of the VULTURE system to perform its intended mission?

What Measures of Suitability (MOS) should be established to ensure successful operation in intended environment?

How do we judge success (Number of successful attacks vice thwarted attacks / total attacks, lack of surface threats to be engaged, boats turned away hourly/daily/monthly, etc)?

C. CAPSTONE PROJECT ORGANIZATION

1. Scoping and Bounding the Project

The initial focus of this project was intended to cover multiple off-shore OPLATs in both the continental US and OCONUS waters subjected to a variety of threats to include air, water surface, and sub-surface attacks. However, due to limitations of time and the vast solution space which such considerations would necessarily involve, it was determined by the VULTURE team and our NPS and NAVAIR advisors that the project would concentrate on the ability of a UAS system to provide viable protection for OCONUS OPLATs against only surface threats utilizing both lethal and non-lethal means. Viability of the system is determined by the intended core stakeholders.

2. Project Team

The team members were from a broad spectrum at NAVAIR and contained a wealth of experience as detailed in Appendix B, Table 23. Current and former personnel from Naval Air Warfare Center Aircraft Division (NAWCAD) were included amongst the team members and for the purpose of this project will be listed with their coworkers as under NAVAIR.

3. Systems Engineering Methodology

The systems engineering methodology is detailed in Figure 2. The Systems Engineering 'V model' was adapted from Blanchard and Fabrycky [5] to meet the needs of the VULTURE team. The project focuses on the left hand of the V model, highlighted in Figure 2 in red, and compares to the adapted methodology utilized by the VULTURE team composed of the blue 'waterfall' pattern also included in Figure 2. This process was determined by group input to adequately address the goal to develop an affordable technology based solution to protect and defend off-shore OPLATs. It was determined that the VULTURE team would interact with the stakeholder to: learn about the situation, bracket the problem, develop/understand the concept of operations, develop and prioritize the requirements prior to developing a concept of alternatives and eliminating through various analyses including modeling and simulation. Then the VULTURE team could conclude and recommend a possible or preferred solution. The structure of the report matches the methodology as described in Table 1.

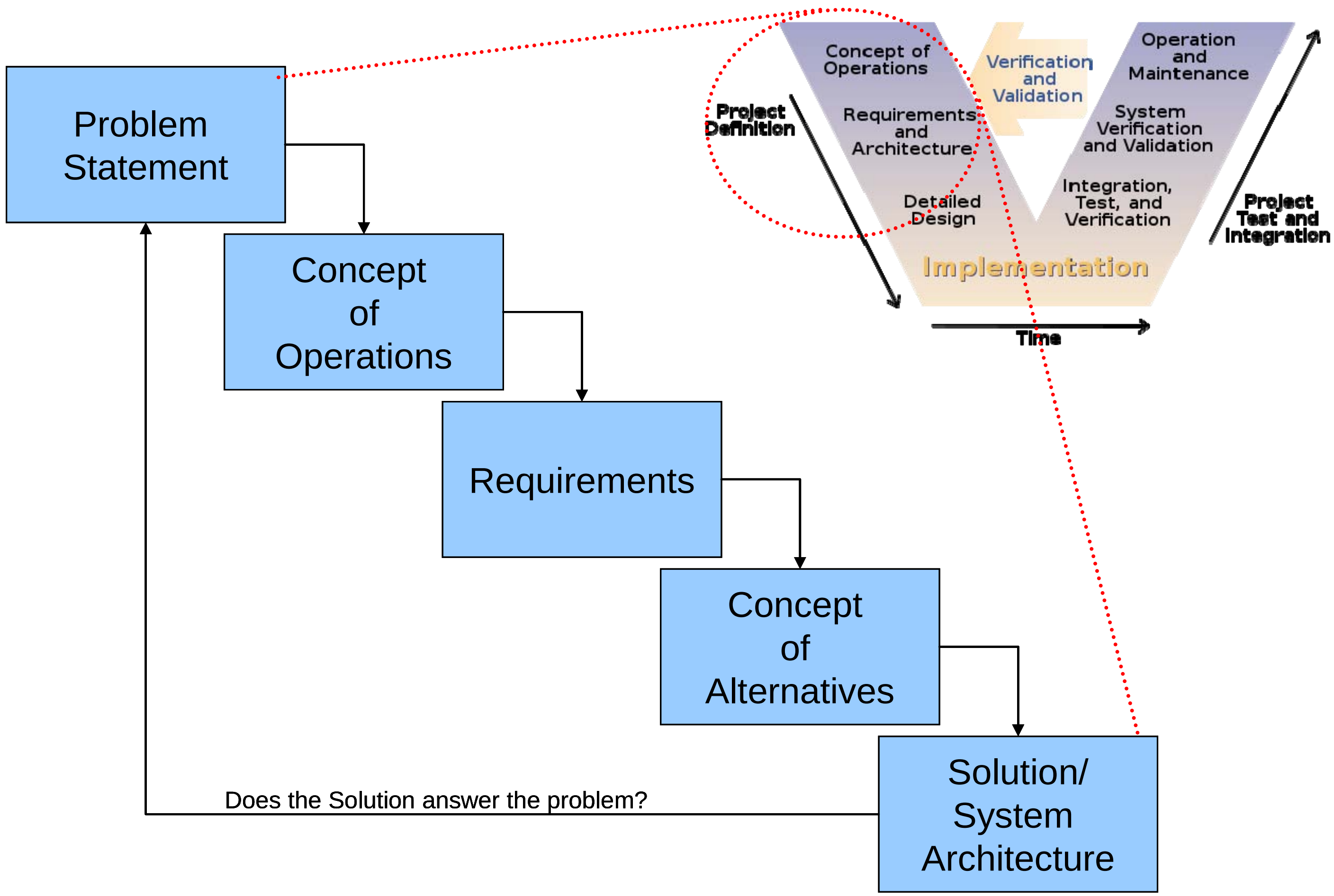

Figure 2: Systems Engineering Method

An important tool used as part of our methodology is Quality Functional Deployment (QFD). The need to clearly link stakeholder input to requirements, design characteristics, system functions, operational objectives, and components of the physical architecture is met through utilization of a complementary set of QFD matrices. Additionally, our use of QFD shows clearly the relative value of each of these requirements and functions, allowing for significant stakeholder input. These QFD matrices are described in thorough detail beginning in section IIIE.

Table 1: Systems Engineering Methodology relation to Report Structure

<table>
<tr><th>VULTURE Approach</th><th>Report Sections</th><th>Report Subsections</th></tr>
<tr><td rowspan="2">Problem Statement</td><td>Introduction</td><td>- Background
- Objective and Research Questions
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<tr><td>Initial Research</td><td>- Problem Statement
- Identification of Stakeholders
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- Stakeholder Inputs
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- Functions vs. Forms
- Mission Analysis
- Operational Activity Model
- Functional Architecture
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- Morphological Matrix
- Performance Rating
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<tr><td rowspan="3">Solution/System Architecture</td></tr>
<tr><td>Synthesis</td><td>- Bang vs. Buck
- Model and Simulation
- Cost Estimation</td></tr>
<tr><td>Conclusions & Recommendations</td><td>- Select Preferred Concept Alternative
- Recommendations</td></tr>
</table>

II. INITIAL RESEARCH

A. PROBLEM STATEMENT

The National Strategy for Maritime Security [1] details several threats in the maritime domain. Specific to terrorism it describes several ‘effective attack capabilities.’ These capabilities include “…explosives-laden suicide boats and light aircraft; merchant and cruise ships as kinetic weapons to ram another vessel, warship, port facility, or offshore platform…[1].” The Joint Publication 3-10, Joint Security Operations in Theater, as listed in the U.S. Navy Maritime Expeditionary Security Force Concept of Operations [6], further defines the various threats to specific levels in detail. A summary review that defines the levels is listed in Table 2.

Table 2: Threat Level and composition

	Typical Threats	Typical Tactics
Level I	Enemy agents, terrorists whose primary mission include espionage, sabotage, and subversion.	Hijacking air, land, and sea vehicles for use in direct attacks; use of Improvised Explosive Device (IED) and Vehicle Borne Improvised Explosive Device (VBIED).
Level II	Small-scale (less than company size equivalent) irregular forces conducting unconventional warfare posing a serious threat to military forces and civilians. Attacks can cause significant disruptions to military operations as well as the orderly conduct of local government and services.	Activities include operations associated with terrorist attacks, listed above (land, air, and sea vehicle hijacking) Establish active espionage networks, collect intelligence, carry out specific missions, develop target lists, and conduct damage assessments of targets struck.
Level III	Force has the capability of projecting combat power by air, land, or sea, anywhere into the operational area.	Examples include airborne, heliborne, and amphibious operations; large combined-arms ground force operations; and infiltration operations.

The scope of this project was restricted to countering the surface threat. Due to the limitations of on-platform Intelligence, Surveillance and Reconnaissance (ISR) capability, there is a limited early positive Identification (ID) capability of possible

surface threats which does not allow for timely and efficient protection of the OPLATs from potential terrorist surface vessel attacks.

B. IDENTIFICATION OF STAKEHOLDERS

A Stakeholder is defined as any entity or organization that benefits from successful implementation of the operational needs statement or is at risk if it fails. Stakeholders can directly or indirectly affect the system design, development and/or implementation.

There are two primary stakeholder entities. The first were conducting the mission of OPLAT protection in the Persian Gulf up until recently:

- Navy Expeditionary Combat Command (NECC)
  CDR Gary Lauck, N9 (Science & Technology) COMNECC
  Charlie Sullivan, Maritime Expeditionary Group 2 (MEG-2)
  CDR John Anderson, N3 (Man, Train, & Equip)

The second entity whose mission is to leverage proven UAS technology, currently utilized for similar mission of infrastructure protection, is:

- Navy Marine Corps Small Tactical Unmanned Air Systems (PMA-263)
  LT Col John Neville, IPT Lead,
  Small Tactical Unmanned Aerial Systems (STUAS)

C. STAKEHOLDER NEEDS

Both NECC and PMA-263 described, a desire for a reliable system that has the ability to detect, engage and neutralize surface threats in a time-critical environment and allow for successful full-time defense of OPLATs [7] [8],. They also stated a need for a system that has well defined MOE that can be used to determine its capabilities and its ability to perform its intended mission. Additionally, they want a system with well defined Measures of Suitability (MOS) that will ensure successful operation in the intended environment.

III. PROBLEM FORMULATION

A. OVERVIEW

Through meetings and conversations with the NECC, and PMA-263, the overall needs of the stakeholder were determined. These interactions developed into a stakeholder survey which fed the systems engineering process as form and function were derived from desired characteristics and requirements.

B. CAPABILITY NEEDS STATEMENT

From discussions with PMA-263 [8], there was a need to meet the threat posed to infrastructure, specifically OPLATs OCONUS. Through the stakeholder needs it was determined that a technological solution was sought to accomplish this mission. This led to a needs statement to maximize the surveillance, positive identification and efficient threat neutralization capabilities regarding possible surface threats while minimizing the manpower footprint.

C. OPERATIONAL CONCEPT AND OV-1

The OV-1 diagram for the VULTURE system, as detailed in Figure 3, describes both the environment and other allied systems with which the VULTURE is expected to interact. These interactions, missions, and general location were gathered from the unclassified Maritime Expeditionary Security Force (MESF) Concept of Operations (CONOPS) [9], given to the project team by one of the stakeholders (NECC). The MESF CONOPS document clarifies the capabilities of the MESF within the Expeditionary Environment far beyond the scope of this project which solely focuses on defense of OPLATs from surface threats. In the OV-1 the VULTURE asset is modeled as a generic UAS. The details of the airborne asset will be discussed later in this report. As the major stakeholder was with Naval Air Systems Command (NAVAIR), specifically PMA 263, the problem was scoped to evaluate only airborne assets in the solution. This eliminated sea based, surface and subsurface, manned and unmanned assets to accomplish the protection of OPLATS mission.

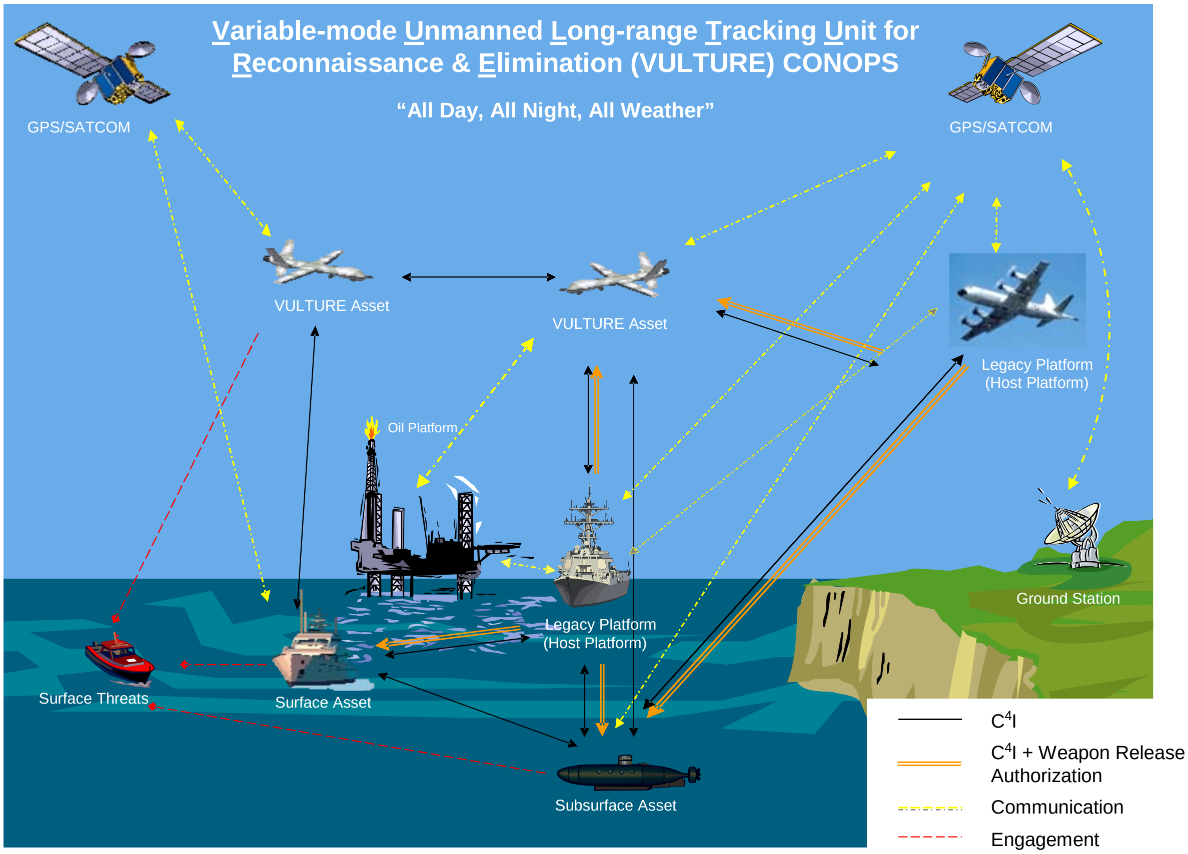


Figure 1: OV-1 of the VULTURE system (generic model UAS)

A. STAKEHOLDER INPUTS

The following section describes the empirical process used to extract top level requirements from the stakeholder, and to analytically transform these requirements into a top level system design approach that allows for proper resource allocation.

A list of top level system requirements were collected from the stakeholders which they based on their needs. The top level system requirements are listed and defined in Table 3.

Table 3: Top Level System Requirements

System Requirements	Definition
Efficiently and Effectively Neutralize Known Surface Threats	Neutralize surface threats quickly and verify.
Communicate Real Time	Data stream to and from UAS.
Conduct Surface Surveillance	Detect and Locate surface contacts.
Conduct Surface Tracking	Maintain track of contacts.
Allow a user to Determine High Priority Targets	Preferred via human operator
Allow a user to Determine Threat Neutralization Method	Human initiated and controlled escalation of force actions.
Conduct a Surface Target Engagement	Upon direction engage target with commanded store.
Persistent On-Station Presence	Capability for extended loiter times.
Survivability	Not easily defeated by direct attack.
Reliable	Probability that UAS can perform as intended throughout its mission.
Available	Probability that the UAS is operational at the beginning of a mission.
Transportable	Has to get to the area of operations
Interoperability	Must communicate with various allied forces.
Conduct positive visual ID of surface contact	Utilize onboard sensors to provide real-time information regarding a surface contact.

These top level system requirements were entered into the Stakeholder Survey matrix shown below in Figure 4, which was in turn given to the stakeholders for reiview and completion. The stakeholders were asked to rank the relative importance of each system requirement against one particular requirement, i.e. "Conduct positive visual ID “surface contact.” This requirement was chosen based on preliminary stakeholder requests, but does not influence the results as the matrix is designed to produce the same results no matter which requirement is chosen. If the stakeholder felt that two requirements were of equal importance, a ‘1’ is highlighted in the matrix. If one If one requirement was deemed more important than another, a number on the more important requirements’ side of the matrix is highlighted.

Stakeholder Survey																		
Conduct positive visual ID of surface contact	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Efficiently and Effectively Neutralize Known Surface Threats.
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Communicate Real Time
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Conduct Surface Surviellance
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Conduct Surface Tracking
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Allow a user to Determine High Priority Targets
Conduct positive visual ID of surface contact	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Allow a user to Determine Threat Neutralization Method
Conduct positive visual ID of surface contact	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Conduct a Surface Target Engagement
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	9	Persistent On-Station Presence
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Survivability
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Reliable
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Available
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Transportable
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Interoperability

Figure 4: Stakeholder (PMA-263) Survey

PMA-263 entered the ratings in the survey which provided the input to the Pairwise Comparison matrix. The Pairwise comparison is essentially an expanded version of the Stakeholder Survey which shows each system requirement's relative importance to every other system requirement, mathematically based on the stakeholder's input to the survey. The results were normalized and each requirement was given a relative weight of importance to the total system.

The output of the Pairwise Comparison (in Figure 5) shows that 'Persistent On-Station Presence' is the most important system requirement indicated by the stakeholders. This was followed in importance by 'Interoperability' and 'Communicate Real Time.'

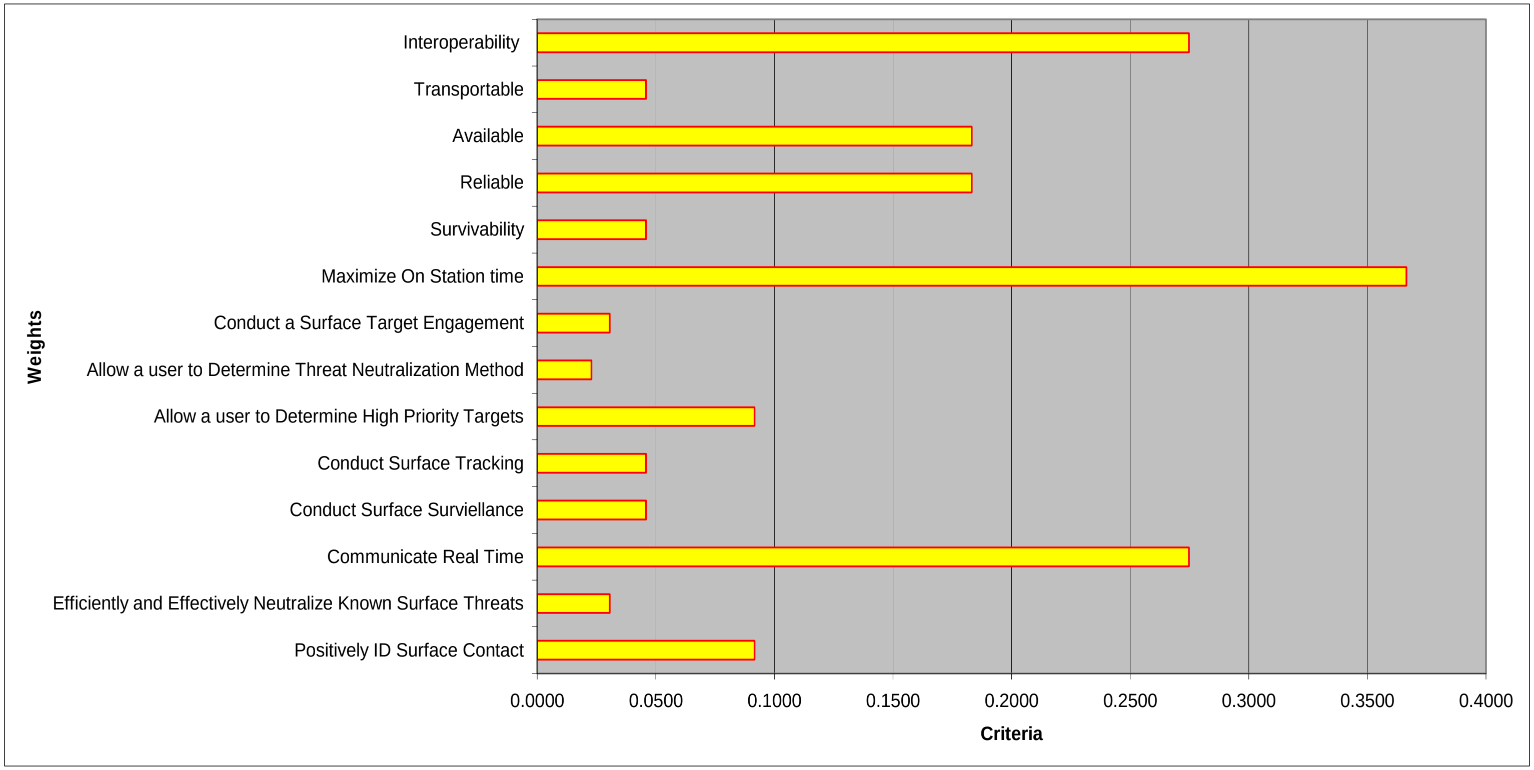


Figure 5: Pairwise Comparison

E. QFD 1 (REQUIREMENTS VS. DESIGN CHARACTERISTICS)

1. Overview

In order to aid in the establishment and prioritization of Technical Performance Measures (TPM), a QFD model was developed. The QFD constitutes a team approach to help ensure that the "voice of the customer" is reflected in the ultimate design. The purpose is to establish the necessary requirements and to translate those requirements into technical solutions [5].

In the QFD 1 shown in Figure 6, the system level requirements, along with their associated weights from the Pairwise Comparison, were aligned with the system design characteristics that will be used to determine the effectiveness of the VULTURE system.

In a combined effort by the stakeholders and the VULTURE team, a list of design characteristics was generated in order to translate the system requirements into measureable performance metrics. The design characteristics are listed and defined in Table 4.

Table 4: Design Characteristic Definitions

Design Characteristics	Definition
Positive Identification (ID)	Percentage of contacts positively identified.
Minimize Threat Response Time	Time for the system to arrive in the area of the threat from anywhere in the battlespace.
Minimize Manpower Footprint	Reduce OPLAT protection manpower.
Maximize Threat Deterrence	Time of uninterrupted OPLAT operation.
Transmit Track Location	Data transfer rates.
Transmit Track Speed	Data transfer rates.
Transmit Track ID	Data transfer rates.
Long Range Target Detection	Successful contact detection and tracking within long range.
Short Range Target Detection	Successful contact detection and tracking within short range.
Track Multiple Targets	The number of targets that can be tracked.
Launch Weapon on/near Target	Successful acquisition of target and deployment of store.
Endurance	The amount of time to loiter over area.
Launch/Recovery Time	The amount of time to takeoff/land.
Survivable	Probability of UAS destruction
Reliable	Mean Time Between Failure (MTBF).
Available	Percentage the system is ready to operate.
Physical Size	Volume of the system/packaging.
Weight	Physical weight of the system/packaging.
Interoperable.	Ability to communicate with friendly forces and assets.

Next, each design characteristic was given one of the following values, determined by its importance in supporting each requirement:

9 – Critical

3 – Important

1 – Necessary

Blank / No value – Marginal importance

Design Characteristics

System Requirement (Whats)	*Weights*	Normalized	1 Positive ID % Pos ID	2 Minimize threat response time Minutes	3 Minimize Manpower Footprint Man Hours Saved	4 Maximize threat deterrence Hrs uninterrupted oil ops/day	5 Transmit Track Location Mb/sec	6 Transmit Track Speed Mb/sec	7 Transmit Track ID MB/sec	8 Long Range Target Detection %	9 Short Range Target Detection %	10 Track Multiple Targets #	11 Launch Weapon on/near Target %	12 Endurance Hours	13 Launch/Recovery Time Min	14 Survivable Probability of Kill (Pk)	15 Reliable MTBF (hrs)	16 Available %	17 Physical size sq-ft	18 Weight lbs	19 Interoperable %	
Positively ID Surface Contact	0.091603053	0.053	9	3		3			9	1	1	1	3									
Efficiently and Effectively Neutralize Known Surface Threats	0.030534351	0.018	3	1		9	9	9	3			1	9	1	1		1	1			1	
Communicate Real Time	0.27480916	0.159	3	3	3		9	9	9	3	3	1									3	
Conduct Surface Surviellance	0.045801527	0.026	1		3	1	1	1	1	9	9	1		3		1	1	1				
Conduct Surface Tracking	0.045801527	0.026	1		1	1	9	9	9			3	3				1	1				
Allow a user to Determine High Priority Targets	0.091603053	0.053	3	3	1		9	9	9	1	3	3					1	1			1	
Allow a user to Determine Threat Neutralization Method	0.022900763	0.013	3	3	1	1	3	3	3				9	1			1	1				
Conduct a Surface Target Engagement	0.030534351	0.018	3	9	1	9	9	9	9				9	1			1	1				
Persistent on-station presence	0.366412214	0.211		9	9	3				1	1	1		9	3	3	3	3				
Survivability	0.045801527	0.026	1										1	1		9						
Reliability	0.183206107	0.106		9	3	3							1	3		1	9	3			3	
Availability	0.183206107	0.106		1	3	3							1	3	3	1	3	9			3	
Transportability	0.045801527	0.026																3	9	9	1	
Interoperability	0.27480916	0.159	3	3	3	1								1			1	1			9	
Check Sum		1.00																				
Goal Value			95	4	24	24	16	16	16	80	80	5	90	10	15	0.5	100	90	700	2,000	95	
Threshold Value			90	6	16	20	8	8	8	70	70	4	85	8	20	0.6	80	85	900	2,500	90	
Weighted Performance			1.8	4.4	3.7	2.0	2.5	2.5	2.9	1.0	1.1	0.7	0.9	2.9	1.0	1.1	2.2	2.3	0.2	0.2	2.6	36.2
Percent Performance			0.050	0.123	0.102	0.054	0.070	0.070	0.080	0.028	0.031	0.019	0.025	0.079	0.027	0.031	0.061	0.063	0.007	0.007	0.073	1.000

Critical - 9
Important - 3
Necessary - 1
Marginal - unmarked

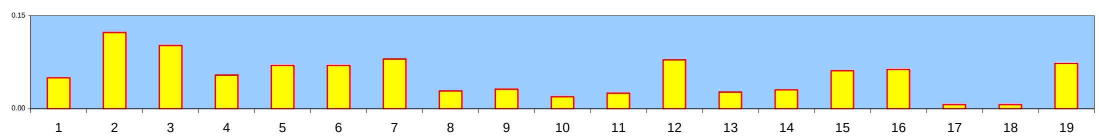


Figure 6: QFD 1

Similar to the Pairwise Comparison, a normalized relative weight was calculated for each design characteristic in QFD 1. The output shows that 'Minimize Threat Response Time' is the most critical design characteristic, followed by 'Minimize Manpower Footprint.'

Notional goal and threshold values were developed for each of the design characteristics listed in QFD 1 to support the initial system development process. The goal and threshold values can also be found in Figure 6. Many of the values were chosen based on a number of metrics for various UAS in size Groups 2-4 (Figure 7) so not to limit or exclude, but include as many solutions as possible. These goal and threshold values are mostly speculative, and can be negotiated and modified during the concept development stage of the program. Some of the metrics worth discussing are the ones that were determined to be a high priority by the stakeholder.

2. Analysis

The highest priority selected by the stakeholder was *Minimizing Threat Response Time,* which was determined to be the amount of time it takes for the system to arrive in the area of the threat from anywhere in the battlespace. In order to determine the speed of the UAS necessary to satisfy the stakeholder's requirements, a number of scenarios were developed by the VULTURE team that represent what the system will likely encounter as defined by the concept of operations; the scenarios were also used in the modeling and simulation of the system. In one scenario, a threat would enter a 5 nautical mile (nm) radius of the OPLATs exactly 180 degrees, and 10 nm away from the UAS. If the threat is traveling at a speed of 40 knots (kts), then it would take it 7.5 minutes to reach the OPLATs assuming constant bearing, decreasing range. The threshold value of 6 minutes for the UAS to intercept was chosen because at that time, the threat would be 1 nm from the platform and that should give the system enough time to acquire, track and eliminate the threat. This translates to a speed requirement of 60 kts for the UAS, which is well within the operating ranges for most of the Group 2-4 UAS; so realistically the UAS would be able to intercept the threat much sooner decreasing the risk of the threat succeeding.

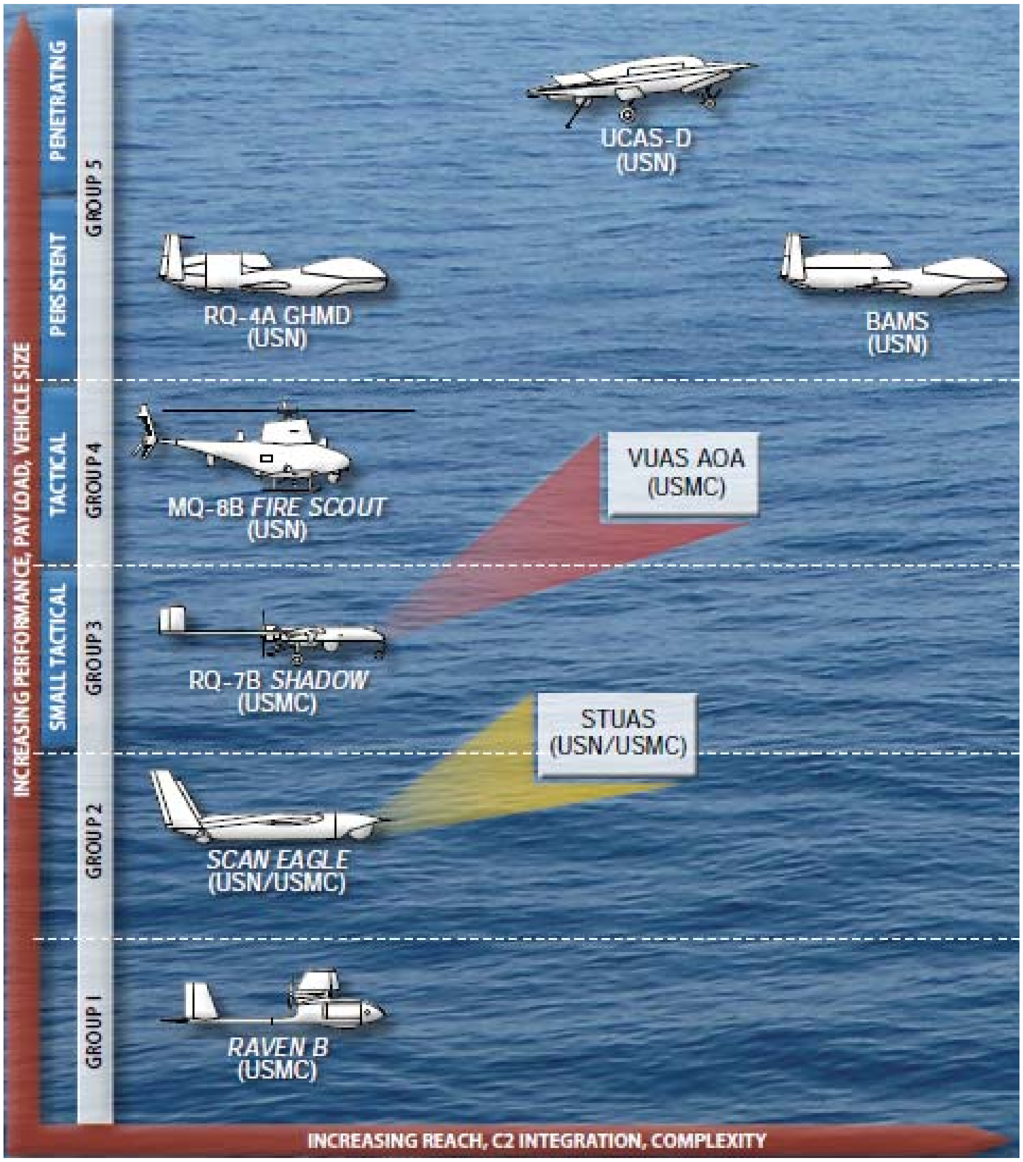


Figure 7: UAS Groups from PMA-263

A concern of the team was to *Minimize or Reduce the Manpower Footprint* to protect OPLATs. At first, saving man hours per day was believed to be easily modeled. Reducing security personnel by incorporating the VULTURE system seemed straightforward. However, the team discovered that the system allows for the possible reduction of one type of personnel (e.g. security guards) yet it may lead to an increase of another type of personnel (e.g. maintenance and UAS operators). This situation was compounded by the sensitive nature of the mission, and therefore a threshold value for manpower footprint or man hours per day was unable to be determined as the stakeholder

(NECC) was incapable on commenting about the specifics of OPLAT defense currently conducted OCONUS.

The team was given background information in the form of the unclassified MESF CONOPS [9]. Contained within the CONOPS were details that did prove useful in understanding the variety of missions, employment of forces, and organization of the MESF. Deployment of the MESF will commonly be of squadron size, while smaller elements (e.g. a security team) are possible depending on the mission. The CONOPS mentions that the smaller elements are not self sustaining and would require support. Teams make up sections that make up detachments. There are different types of detachments described in the CONOPS that are relevant to the project, and three were included in our design: 1 Communications Detachment, 1 Sensor Detachment, and 1 Security Detachment. Each detachment has its own chain of command: Officer In Charge (OIC), Assistant Officer In Charge (AOIC), and Senior Enlisted (SEL). Their breakdown is listed in Table 5.

Table 5: MESF Detachment Personnel

Detachment	**Communication**	**Sensor**	**Security**
OIC	1	1	1
AOIC		1	1
SEL		1	1
Personnel	15	57	72
Total	**16**	**60**	**75**

Although each of these detachments can be further subdivided, it is dependent on the mission requirement. Therefore at most 151 personnel would be consumed with protecting a number of OPLATs (exact number unknown). The goal then is to demonstrate through analysis that the VULTURE UAS can integrate into the MESF structure and decrease the number of deployed personnel. Many of the UAS in Group 2-4 can operate for at least 8 hours, which could translate to a reduced number of overall personnel still required to protect the OPLATs.

Transmitting Data was another high priority for the stakeholder (Interoperability and Communicate Real Time in Figure 5), so a threshold value of 8 Mb/sec was chosen

to allow sufficient bandwidth for streaming video and uninterrupted data flow between the UAS and a ground control station.

As mentioned the design characteristic of *interoperability* was rated highly by the stakeholder. Therefore to fulfill that requirement, the VULTURE system shall be able to operate across multiple services and interest groups to satisfy the Joint Interoperability Test Command (JTIC) certification requirements. Specific requirements are determined by JTIC, and depend on current technology levels. For this reason, the interoperability threshold was set at 90% with an objective of 95%, but would be finalized upon JTIC's feedback.

Reliability and Availability of the VULTURE system was also a significant factor. These characteristic metrics were set to values comparable to some of the DoD's current UAS. The reliability of the UAS is expressed in MTBF, which is defined as the ratio of hours flown to the number of maintenance-related cancellations encountered. In QFD 1, the MTBF goal and threshold values are 100 and 80 hours, respectively. The Operational Availability (Ao) of the UAS is defined as 'the probability that the system will operate when called upon in an operational environment [5].' Both the weight and physical size metrics are based on the weight and size of current Group 2-4 UAS. The goal and threshold values for weight are 2000 lb and 2500 lb, respectively.

A relatively high threshold value of 90% with a goal value of 95% was selected for *Positive target ID* because it's important that the VULTURE system and user is able to discern between a threat and a friendly contact in order to prevent inadvertent elimination of a non-hostile craft (e.g. civilian casualties). This also ties to the ability of the system to be able to launch weapons on or near the target. In order for the system to be effective, it must ultimately be able to eliminate or deter a threat, so reasonably high goal and threshold values (e.g. 85% & 90%) for launching weapons on/near a target were set.

Since the *Survivability* of the UAS against rockets, missiles and small arms fire is of little concern to the stakeholder, fairly high probability of kill given a hit ($P_{k/h}$) values were established for the system, which translates to a low probability of survival if the VULTURE is hit by a threat due to a relatively large vulnerable area. Because the UAS will normally be operating at altitudes outside the range of small arms fire, the

probability of the VULTURE being hit is low, so it will have a high probability of survival. Since the UAS will have minimal survivability systems constraints placed upon it, the overall weight will be lower, which allows for trade space in other areas.

Short and Long Range Target Detection were not rated very highly either, so the threshold and goal values were set to 70% and 80% respectively so it would not become a show-stopper in the development of the system. The stakeholder wanted the system to be able to simultaneously track multiple targets, so the threshold and goal values were set to 4 and 5 targets, respectively.

The last design characteristic for the system is *Launch and Recovery Time*. Since the system will use multiple UAS to provide persistent surveillance, one UAS will most likely be in the air when a second one is launched, which makes this metric a low priority. Threshold and goal values of 20 and 15 minutes were set for the launch and recovery of the VULTURE system.

F. QFD 2 (DESIGN CHARACTERISTICS VS. FUNCTIONS)

In the QFD shown in Figure 8, the system design characteristics, along with their associated weights from QFD 1, were aligned with the system level functions required of the VULTURE system. This step on the QFD model provided the traceability between the system requirements and critical system components. A list of top-level functions was developed by the stakeholders and VULTURE team members. The top-level functions are: Neutralize Surface Threat, Perform Command & Control (C^2), Conduct Surface Surveillance, and Maintain On-Station Presence. Neutralization of the Surface Threat is defined as deterring or destroying a surface contact as it approaches the OPLATS according to the Rules Of Engagement (ROE) established by the relevant command. C^2 is almost a misnomer as the UAS is receiving instructions and relaying information. The UAS itself is not exercising C^2 but operating under human control. The Conduct of Surface Surveillance is closely related to Maintain On-Station Presence which are interrelated as the UAS must be on station to accomplish the surveillance. The surveillance will be accomplished through the utilization of onboard sensors. On-Station Presence will be maintained by a ‘loiter ability’ for example a ‘maximum endurance’ capability in the performance of an engine onboard the UAS.

Each function was given one of the following values by the stakeholder, determined by its importance in implementing each design characteristic:

9 – Critical

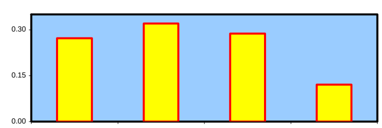
3 – Important

1 – Necessary

Blank / No value – Marginal importance

In the same manner as the previous QFD, a normalized relative weight was calculated for each system function in QFD 2. The results show that the most critical function is “Conduct Surface Surveillance.” This is followed closely by “Perform Command and Control” and “Maximize On-Station Presence.”

Design Characteristics	Weights		Functions 1: Maintain On-Station Presence	2: Conduct Surface Surveillance	3: Perform Command & Control (C2)	4: Neutralize Surface Threat	
Positive ID	0.050	0.050	**3**	**9**	**3**	**3**	
Minimize threat response time	0.123	0.123	**9**	**9**	**3**	**1**	
Minimize Manpower Footprint	0.102	0.102	**3**			**3**	
Maximize threat deterrence	0.054	0.054	**3**	**3**	**3**	**9**	
Transmit Track Location	0.070	0.070		**3**	**9**		
Transmit Track Speed	0.070	0.070		**3**	**9**		
Transmit Track ID	0.080	0.080		**3**	**9**		
Long Range Target Detection	0.028	0.028	**1**	**9**	**1**		
Short Range Target Detection	0.031	0.031	**1**	**9**	**1**		
Track Multiple Targets	0.019	0.019		**9**	**1**	**1**	
Launch Weapon on/near Target	0.025	0.025			**3**	**9**	
Endurance	0.079	0.079	**9**	**3**			
Launch/Recovery Time	0.027	0.027	**3**	**1**			
Survivable	0.031	0.031	**1**	**1**			
Reliable	0.061	0.061	**3**	**1**	**1**		
Available	0.063	0.063	**3**	**1**	**1**		
Physical size	0.007	0.007				**1**	
Weight	0.007	0.007	**1**				
Interoperable	0.073	0.073			**3**		
Check Sum	1.000	1.00					
Weighted Performance			3.0	3.5	3.2	1.3	11.0
Percent Performance			0.272	0.320	0.288	0.120	1.000



Critical - 9
Important - 3
Necessary - 1
Marginal - unmarked

Figure 8: QFD 2

G. QFD 3 (FUNCTIONS VS. FORMS)

In the QFD 3 shown in Figure 9, the system functions, along with their associated weights from QFD 2, were aligned with the physical subsystems needed to implement the VULTURE system. These subsystems were determined by the VULTURE team members who were Subject Matter Experts (SME) along with feedback from a stakeholder (PMA 263) regarding current subsystem technology needed to accomplish the mission.

As before, a list of subsystems was put together by the stakeholders and the VULTURE team based on currently operating systems. The various subsystems include: Data Processing, Weapons, Surveillance, C^2, Network, Propulsion, Launch/Recovery, Communications, and Air Vehicle. The Data Processing Subsystem will receive information from other subsystems via the Network and determine which of the subsystems will receive the information. For example, Surveillance provides images of a contact via the Network to Data Processing which sends the information to Communications where the operator directs through C^2 the Air Vehicle to change course and increase power through the Propulsion subsystem and get within Weapons range. This is a very simplified example but it shows the importance of the interrelationships that exist. Each subsystem was given one of the following values, determined by its importance in implementing each system function:

9 – Critical

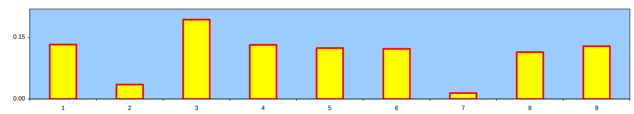
3 – Important

1 – Necessary

Blank / No value – Marginal importance

In the same manner as before, a normalized relative weight was calculated for each subsystem in QFD 3. The results show that the most critical subsystem is the Surveillance Subsystem, while the least critical is the Launch and Recovery Subsystem.

Form (Components)			1	2	3	4	5	6	7	8	9	
Functions	*Weights*		**Data Processing SS**	**Weapons SS**	**Surveillance SS**	**C2 (ISR)**	**Network**	**Propulsion SS**	**Launch/Recovery SS**	**Communications SS**	**Air Vehicle SS**	
Maintain On-Station Presence	0.272	0.272			**9**	**3**	**3**	**9**		**1**	**9**	
Conduct Surface Surveillance	0.320	0.320	**9**		**9**	**1**	**1**	**3**	**1**	**1**	**1**	
Perform Command & Control (C2)	0.288	0.288	**3**		**1**	**9**	**9**			**9**	**3**	
Neutralize Surface Threat	0.120	0.120	**3**	**9**	**3**	**3**	**1**	**3**	**1**	**3**	**3**	
Check Sum		1.00										
Weighted Performance			4.1	1.1	6.0	4.1	3.8	3.8	0.4	3.5	4.0	30.8
Percent Performance			0.133	0.035	0.194	0.132	0.125	0.122	0.014	0.115	0.129	



Critical - 9
Important - 3
Necessary - 1
Marginal - unmarked

Figure 9: QFD 3

As discussed previously, the process described in this section allowed the derivation of a top level system design approach. The output from QFD 3, for instance, shows that a significant portion of effort and resources should be concentrated on development of the Surveillance Subsystem since that traced most directly to the stakeholder's number one system requirement. On the other hand, while the Launch and Recovery Subsystem is clearly important to a functioning VULTURE system, the lack of traceability to highly ranked system requirements shows that it is unnecessary to expend resources to develop more than a baseline solution.

H. MISSION ANALYSIS

Once the stakeholder needs were identified and the functions and attributes were assigned to them via the QFD, a mission statement was required along with a CONOPS. A mission analysis was performed for the VULTURE system using the Joint Operations Concepts Development Process (JOpsC-DP) [10]. Figure 10 shows the DoD Joint Operations Concepts (JOpsC) family. The JOpsC family consists of a Capstone Concept

for Joint Operations (CCJO), Joint Operating Concepts (JOCs), Joint Functional Concepts (JFCs) and Joint Integrating Concepts (JICs). Capabilities are developed using this strategy to conduct military operations.

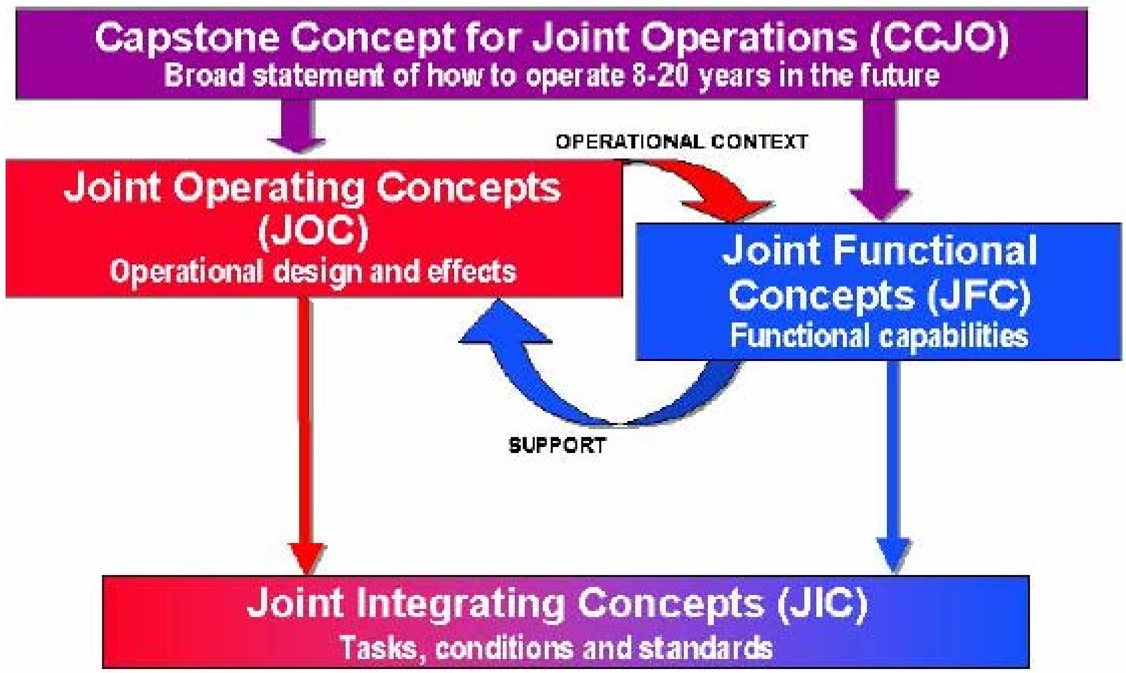


Figure 10: Joint Operations Concepts Family

Each block in Figure 10 is described in Appendix C and was obtained from the JOpsC-DP instruction [10].

1. Joint Operations Concept

Various elements of the Joint Operations Concepts are discussed throughout this document as shown in Table 6.

Table 6: Joint Operations Concepts tracking

Capstone Concept for Joint Operations	• Operational concept (paragraph C) • OV-1 diagram (figure 3)
Joint Operating Concepts	• CONOPS (paragraph H.5) • Operational activity model (paragraph I)
Joint Functional Concepts	• Functional architecture (paragraph J)
Joint Integrating Concepts	• Universal Joint Task List (paragraph H.2) • Universal Naval Task List (paragraph H.3)

The CONOPS and the OV-1 diagram lay the foundation for how the VULTURE system will be employed. Furthermore, the CONOPS along with the operational activity model describe how a joint force commander could conduct operations using the VUTLURE system within a military campaign. Additionally, the functional architecture identifies the operational-level capabilities required to support VULTURE operations. Finally, the Universal Joint Task List and the Universal Naval Task List describe specific missions and tasks that VULTURE would satisfy upon development and deployment.

2. Universal Joint Task List

Table 7 contains the elements from the Universal Joint Task List (UJTL) database [11] that were related to the Joint Capabilities Area (JCA), "Protection". Further details of the JCA definitions and elements are listed in Appendix C. The UJTL is a library of tasks, which serves as a foundation for capabilities-based planning across the range of military operations, as described by the *Chairman of the Joint Chiefs of Staff Manual* 3500.04E [12]. It is utilized for the development of joint mission-essential task lists in identifying required capabilities for mission success. The items highlighted in Table 7 partially apply to the VULTURE system. The UJTL is accompanied by the Universal Naval Task List (UNTL) [13].

Table 7: Protection UJTL Elements

ST 6 Coordinate Theater Force Protection	
ST 6.1	*Provide Theater Aerospace and Missile Defense*
ST 6.1.1	*Process Theater Air and Space Targets*
ST 6.1.2	*Provide Airspace Control Measures*
ST 6.1.3	Establish Theater Space System Force Enhancement Operations
ST 6.1.4	*Organize and Coordinate Theater Air Defense*
ST 6.1.5	Organize and Coordinate Theater Missile Defense
ST 6.1.6	*Support Tactical Warning and Attack Assessment in Theater*
ST 6.1.7	Conduct Ballistic Missile Defense Operations
ST 6.2	Coordinate Protection for Theater Forces and Means
ST 6.2.1	Coordinate the Preparation of Strategically Significant Defenses
ST 6.2.2	Coordinate the Removal of Strategically Significant Hazards
ST 6.2.3	Protect Use of Electromagnetic Spectrum
ST 6.2.4	Ensure Acoustic Protection
ST 6.2.5	Establish and Coordinate Positive Identification Procedures for Friendly Forces in Theater
ST 6.2.6	Establish and Coordinate Security Procedures for Theater Forces and Means
ST 6.2.6.1	Establish and Coordinate Counter- Reconnaissance Theater-Wide
ST 6.2.6.2	Establish and Coordinate Protection of Theater Installations, Facilities, and Systems
ST 6.2.6.3	Establish and Coordinate Protection of Theater Air, Land, and Sea Lines of Communications (LOCs)
ST6.2.6.4	Establish and Coordinate Theater-Wide Counterintelligence Requirements
ST 6.2.7	Conduct Personnel Recovery

3. Universal Naval Task List

Finally, the mission from the UNTL that relates to the items highlighted in Table 7 is shown in Figure 11. Attacking surface targets at sea may be conducted with various types of weapons such as torpedoes, air dropped or air launched weapons, or sea mines. The VULTURE system for this analysis will only concentrate on surface threats.

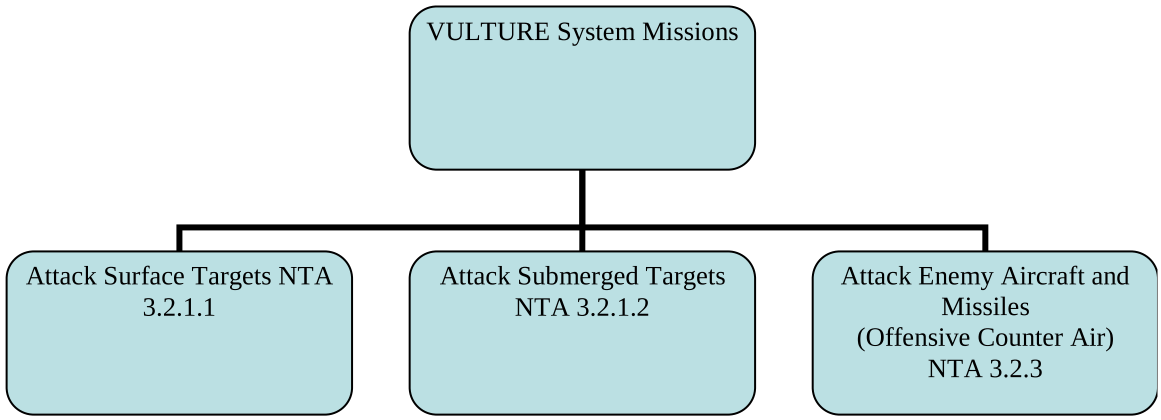


Figure 11: Universal Naval Task List Missions

4. Mission Statement

The joint operations concepts development process was used to perform mission analysis for the VULTURE system. The following mission statement was derived from this analysis:

> *<u>The mission of the VULTURE system is to provide defense of sea-based oil platforms from attack by surface threats thereby protecting critical infrastructure and key resources of the United States.</u>*

5. Concept of Operations

The VULTURE system will be operated by civilian and military security forces from the OPLATs. It will be operating in a maritime environment under the following conditions:

- Day, night, or low-visibility (rain/fog)
- Sea state: <4
- Water Temperature: 32^{o} F to 105^{o} F
- Clouds/precipitation (limited visibility)
- Winds: <45 knots
- Air Temperature: 0^{o} F to 120^{o} F

Security personnel will deploy the VULTURE system to provide situational awareness at distances from the OPLATs sufficient to neutralize detected threats. The VULTURE system will perform Intelligence, Surveillance, and Reconnaissance (ISR) functions of contacts within the local area of the OPLATs within its area of operation. It will process data and transmit it to provide alerts and cueing so the operators can

accurately ascertain friendly contacts from threats. Once a threat is detected, the VUTLURE system will track the threat and deploy non-lethal and/or lethal weapons under human C^2, until the threat is deterred or destroyed. The operators will follow established ROE while in operation. Security forces will utilize the VULTURE system to counter a surface threat scenario as shown in Figure 12. A small surface vessel or personal water craft is maneuvered on a collision course with the OPLAT. Its purpose is to either detonate explosives on impact or permit personnel to board the OPLAT. This vessel would most likely appear to be a local fishing or recreational vehicle. It may engage the OPLAT during the day or night; however, it would most likely occur during calmer sea states.

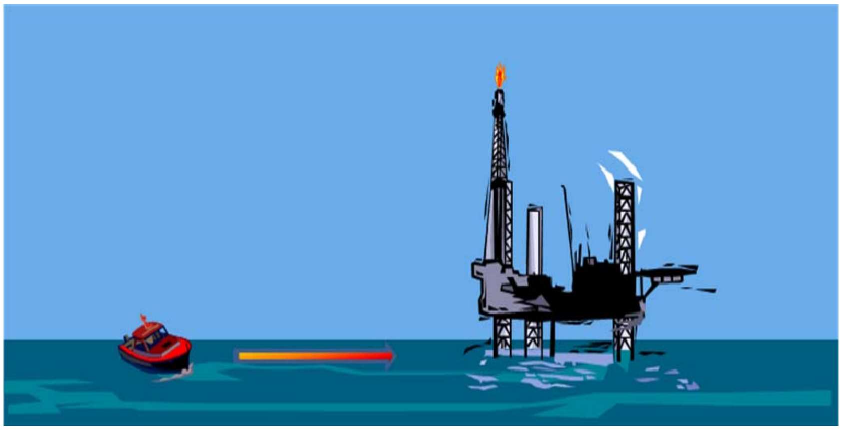


Figure 12: Threat Engagement of Oil Platform

I. OV-5 OPERATIONAL ACTIVITY MODEL

Figure 13 shows the OV-5 diagram which describes the operations that are normally conducted in the course of achieving a mission. At first, there must be a request for the VULTURE system. Next, the mission to protect the forces is started. Thirdly, surface contacts need to be detected, and they need to be tracked. While they are being tracked, these contacts are assessed to determine whether they are threats. Once a threat is determined, it is diligently tracked with the purpose of targeting. Next, the threat is engaged to either deter or neutralize the threat. Afterward, the effectiveness of this engagement is assessed to ensure the target is no longer a threat to the OPLATs. Finally, the mission ends, and the VULTURE system is recovered.

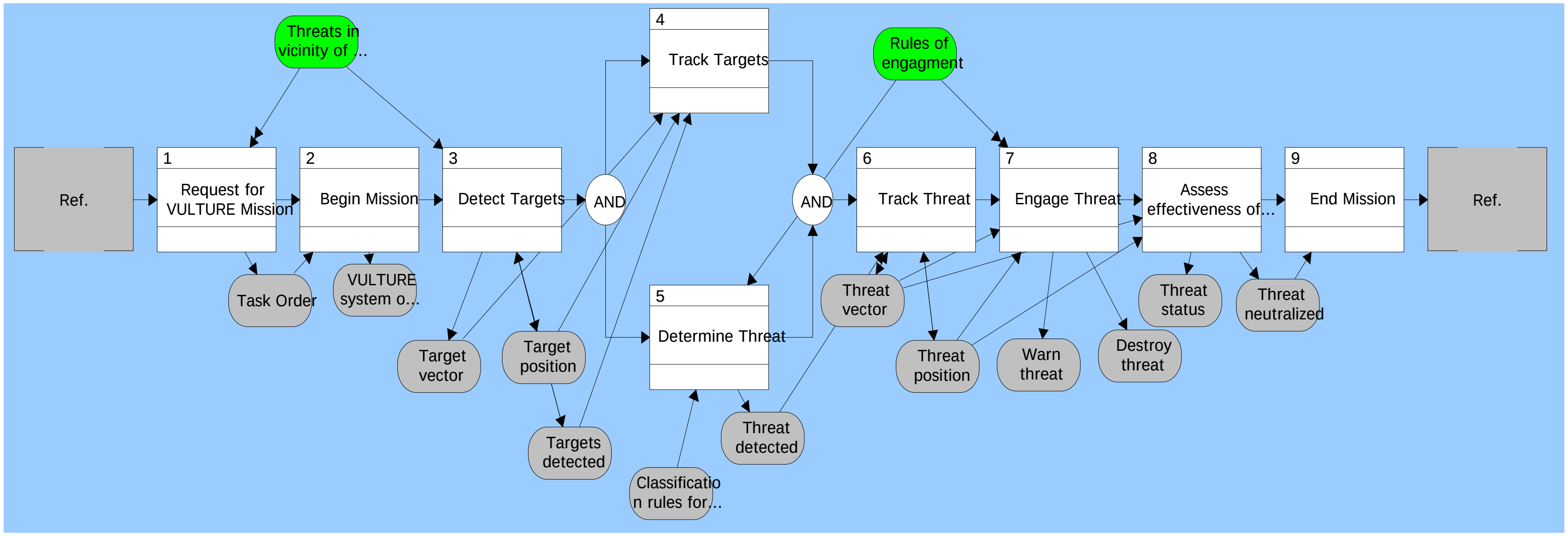


Figure 13: VULTURE OV-5 Diagram

J. FUNCTIONAL ARCHITECTURE

The VULTURE system architecture was developed using the Vitech Model-Based Systems Engineering Approach utilizing CORE 6.0. CORE is a database program that catalogues the system architecting process. Various data elements were completed in the folders and subfolders providing a complete element definition in a tabular, text format. These data elements can be displayed in an element-relationship diagram replacing the textual representation of an element's relationships with a graphic representation. Output reports can be generated that align with the defined DoD Architectural Framework [14].

1. SV-4a List of System Functions

Figure 14 shows the hierarchical view of the top-level VULTURE system functions. Figure 15 through Figure 18, for better readability, show the system's sub-elements to the third tier of the overall VULTURE system. The VULTURE system is made up of the following tier 2 functions: (1) *maintain on-station presence* (Figure 15); (2) *conduct surface surveillance* (Figure 16); (3) *perform command and control* (Figure 17); and (4) *neutralize surface threats* (Figure 18), each containing a unique set of third tier functions. For maintain on-station presence, the VULTURE system must be operating in proximity to the OPLATS performing its mission. While operating, it conducts surface surveillance of the nearby area looking for contacts and or threats. At the same time, an operator is always performing command and control of the system. Finally, the VULTURE system will neutralize surface threats once ordered following the ROE.

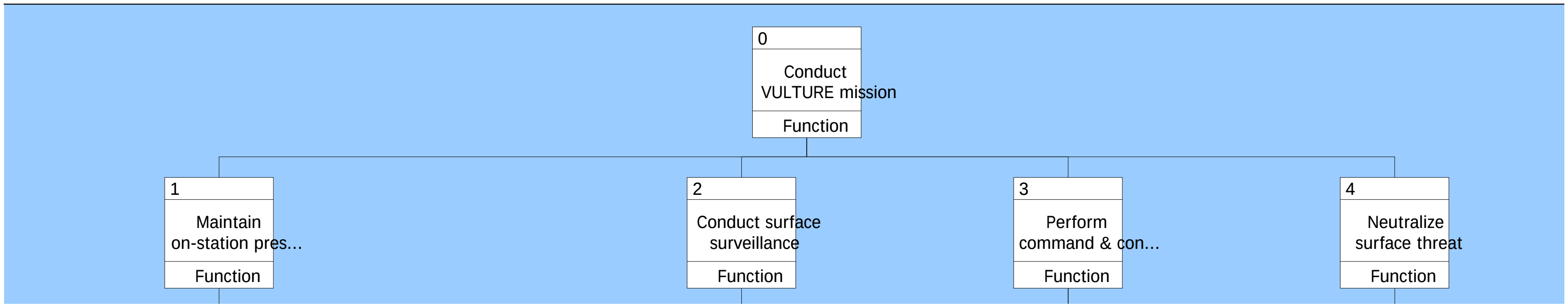


Figure 14: VULTURE SV-4a Diagram

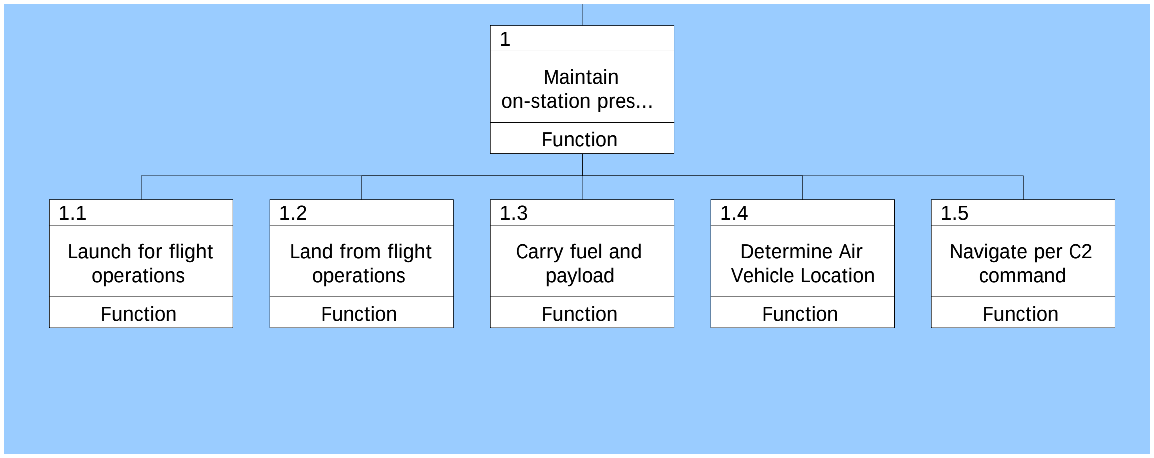


Figure 15: Maintain On-Station Presence Function

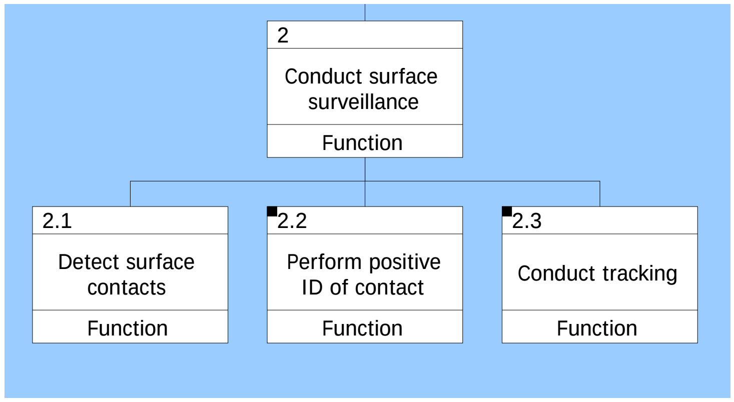


Figure 16: Conduct Surface Surveillance Function

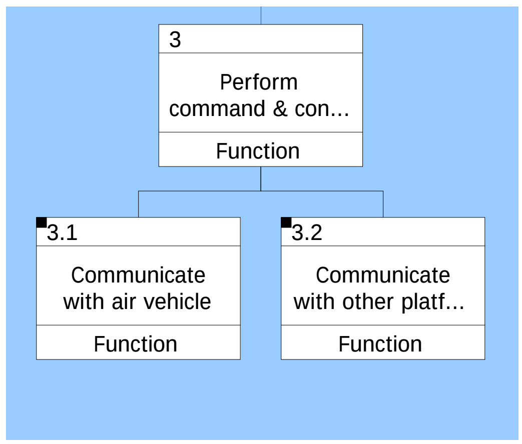


Figure 17: Conduct Command and Control Function

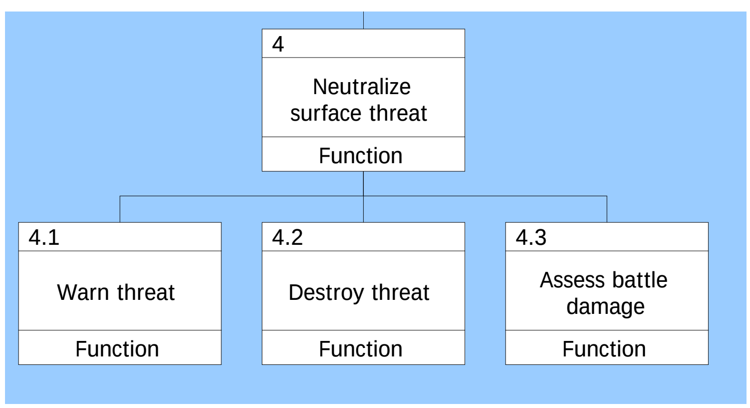


Figure 18: Neutralize Surface Threat Function

2. SV-4b System Functional View

An Enhanced Functional Flow Block Diagram (EFFBD) for the VULTURE mission is shown in Figure 19 which depicts the sequence of activities that must occur in

order for the system to successfully complete each of the top-level functions. All inputs, outputs, and triggers are illustrated for these various functions. The gray color boxes identify the inputs and outputs, and the green boxes represent the triggers. Each of the functions within the EFFBD was linked to items necessary to move into the next functional block. For example, the tier 2 level function "Maintain on-station presence" will require fuel in order to be accomplished. Furthermore, it must provide the location of the air vehicle in order for the "Perform command and control" function to properly operate. The trigger "Threat Assessment" is required by the "Perform command & control" function in order for the "Neutralize surface threat" function to be accomplished.

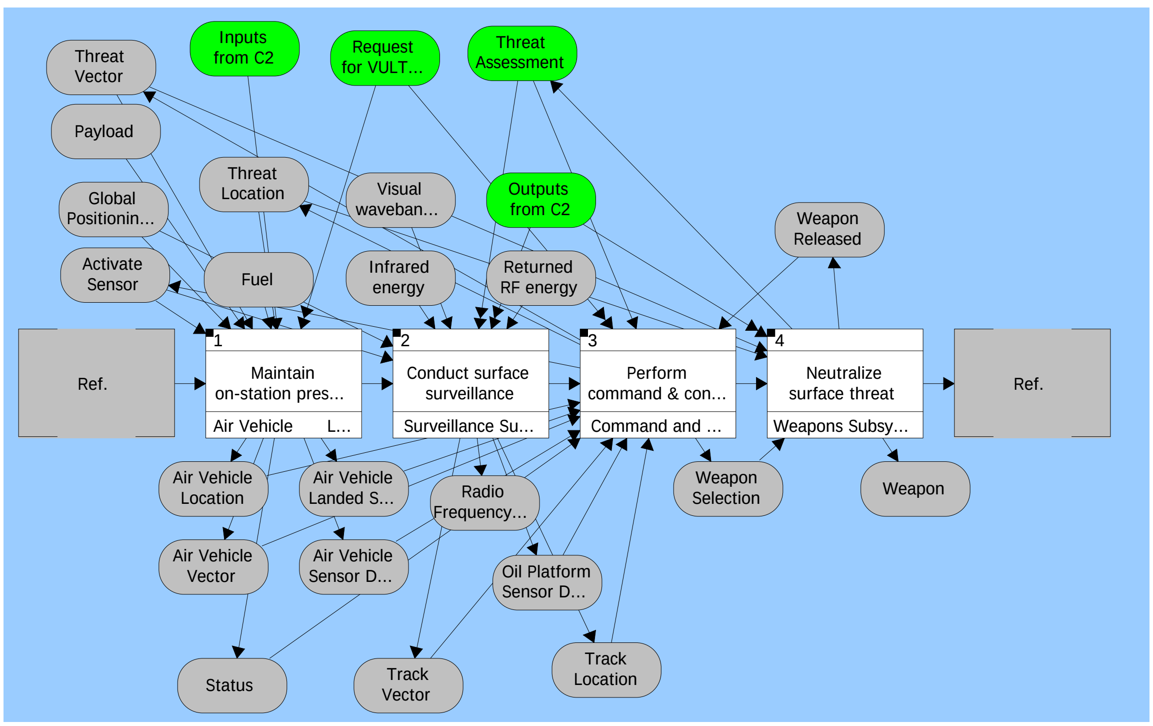


Figure 19: VULTURE SV-4b Diagram

3. SV-5 Operational Activity to System Function Traceability Matrix

Table 8 contains the VULTURE system SV-5 matrix which depicts the mapping of operational activities to system functions and components as shown by the "X" mark in the blocks. This matrix identifies the transformation of an operational need into a purposeful action performed by a system. The operational activities were previously discussed in section I with the OV-5 operational activity model. The function column

identifies all the top-level functions that were shown in the previous figures plus all of the lower-level functions too which are shown in Appendix D. Finally, the components column shows which item will perform the function and operational activity thus linking all three areas together. Plus, the SV-5 matrix provides the linkage from this section with the functions to section IV which discusses the physical architecture in detail.

Table 8: VULTURE SV-5 Matrix

Component	Function	Operational Activity								
		Assess effectiveness of engagement	Begin Mission	Detect Targets	Determine Threat	End Mission	Engage Threat	Request for VULTURE Mission	Track Targets	Track Threat
Air Vehicle	Carry fuel		X							
	Carry fuel and payload						X			
	Carry sensors	X								
	Carry weapons						X			
	Maintain on-station presence		X			X	X			
Command and Control Subsystem (ISR)	Classify contact as threat				X					X
	Classify contact non-threat				X					
	Communicate with air vehicle			X			X			
	Determine Location						X			
	Navigate per C^2 command						X			
	Perform command & control (C^2)		X	X		X	X	X		
	Perform positive ID of contact			X	X					
Communications	Communicate with allied forces					X		X		
	Communicate with contacts						X			
	Communicate with other platforms					X		X		
	Perform command & control (C^2)		X	X		X	X	X		

Component	Function	Operational Activity								
		Assess effectiveness of engagement	Begin Mission	Detect Targets	Determine Threat	End Mission	Engage Threat	Request for VULTURE Mission	Track Targets	Track Threat
Data Processing Subsystem	Communicate with allied forces					X		X		
	Perform command & control (C^2)		X	X		X	X	X		
Launch and Recovery Equipment	Begin mission		X							
	Complete mission					X				
	Maintain on-station presence		X			X	X			
Network	Communicate with allied forces					X		X		
	Perform command & control (C^2)		X	X		X	X	X		
Propulsion	Maintain on-station presence		X			X	X			
Surveillance Subsystem	Assess battle damage	X								
	Conduct surface surveillance	X	X	X	X				X	X
	Conduct tracking								X	X
	Detect surface contacts			X						
	Report contact bearing								X	X
	Report contact position								X	X
	Report contact speed								X	X
Weapons Subsystem (anti-surface)	Destroy threat						X			
	Neutralize surface threat	X					X			
	Release weapon						X			
	Select weapon						X			
	Warn threat						X			

4. Conclusion

The VULTURE system architecture was developed using the Vitech CORE 6.0 software program which was effectively used to identify top-level functions and then decompose them into lower levels. Interrelationships between the functions, components, and operational activity were shown.

K. INTERFACE

1. SV-4c Logical Interface View

A N^2 diagram is shown in Figure 20 for the VULTURE system functions. The top-level functions are aligned diagonally from top left to bottom right. The inputs and outputs of the functions are also identified going horizontally between the functions. Each of these top-level functions has inputs and outputs going between them which show their interrelationships. For example, the function “Maintain on-station presence” will input the item “Payload”. It will output “Air Vehicle Location” which will input into the “Perform Command & Control (C^2)” function. The function “Conduct Surface Surveillance” will input the item “Global Positioning Data” and will output the item “Track Vector” which goes to the “Perform Command & Control (C^2)” function. The function “Neutralize surface threat” will receive the input “Weapon selection” from the “Perform Command & Control (C^2)” function and it will output the item “Weapon”. Furthermore, it will provide an output of “Weapon Released” which will be reported back to the “Perform Command & Control (C^2)” function.

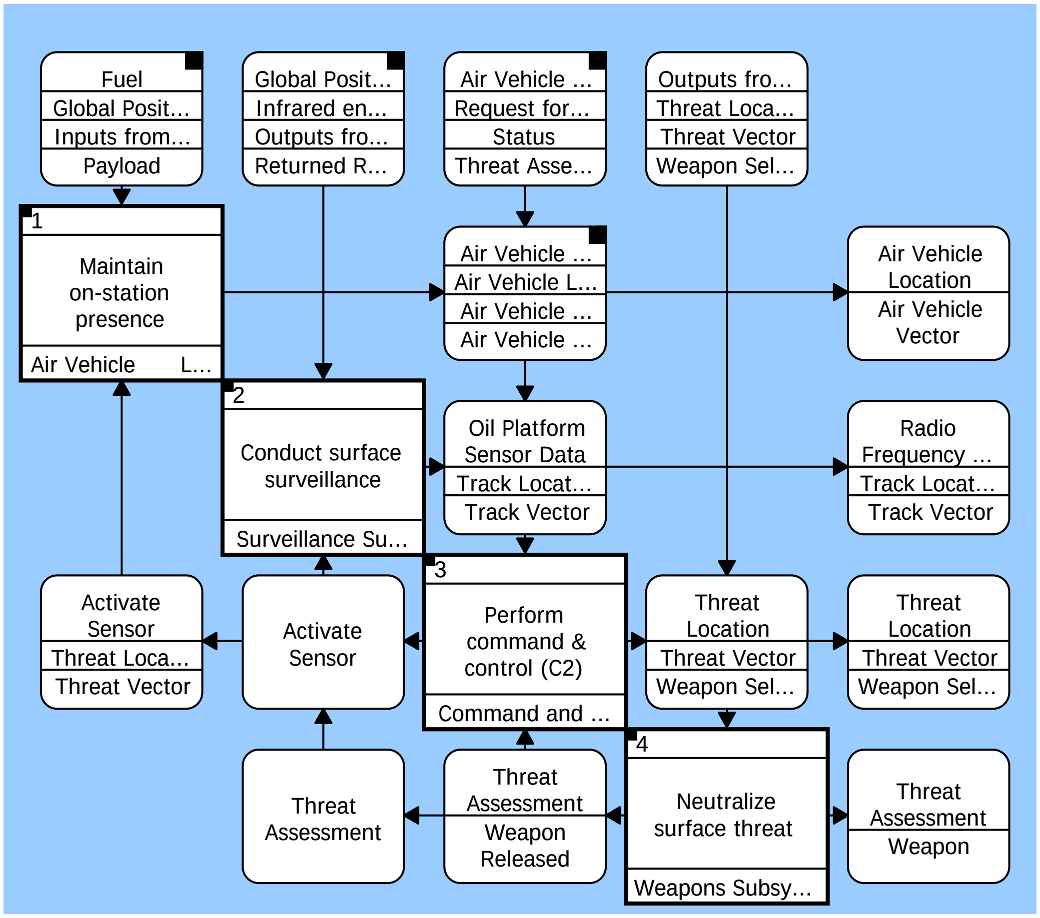


Figure 20: VULTURE N^2 Diagram

2. Level 0 Diagram

An Integration Definition for Function Modeling (IDEF) level 0 diagram for the VULTURE system is shown in Figure 21. The top-level function "Conduct VULTURE mission" is shown with its inputs on the top, outputs on the right side, and physical support on the bottom of the figure. The input "Request for VULTURE support" is the trigger which starts the system. The physical "VULTURE System" supports the mission. Finally, the output of the system is that the threat is deterred. Inputs and outputs from the system are identified along with the signals passed between the various top-level functions. A decomposition of these top level functions into IDEF level 1 diagrams is illustrated in Appendix D.

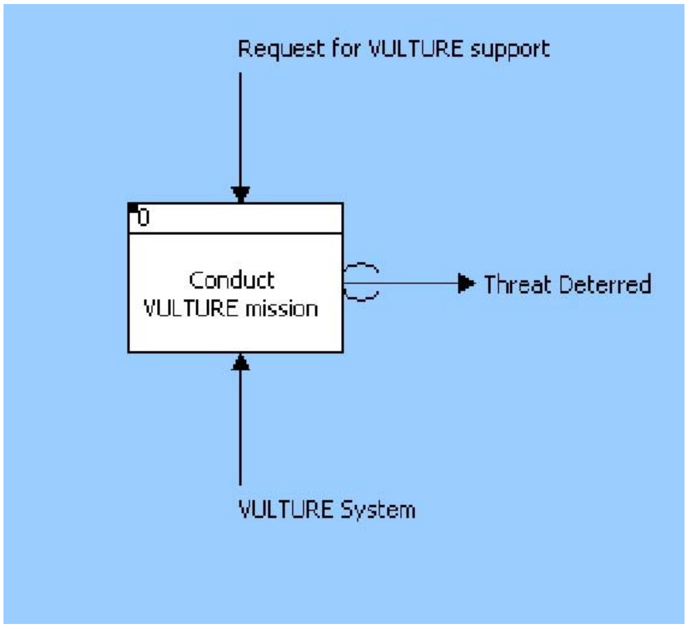


Figure 21: VULTURE Functional IDEF0 Diagram

IV. ALTERNATIVES GENERATION AND ANALYSIS

A. METHOD

The Analysis of Alternatives (AoA) for the VULTURE system was conducted by the team during the design and analysis phase. Solutions for the AoA were generated based on the engineering and programmatic experience of the team members in specific areas, stakeholder input, research of published materials, and speaking with SME of specific types of subsystems and components (e.g. EO/IR etc.).

An air vehicle system was chosen as the starting point for this analysis. As mentioned previously, no analysis was conducted regarding a surface or subsurface vessel (manned or unmanned) for this mission. The VULTURE system is intended to be developed as a UAS which can provide persistent ISR capability and, ultimately, a weapons-employment response through the use of lethal and/or non-lethal engagement of threats to protect existing OCONUS OPLATs. This system is intended to enhance the efforts of the Navy and Coast Guard which are currently protecting allied and host nation OPLATs around the world. Having a UAS that is able to provide the above capabilities will at least increase the efficiency of the OPLAT mission and at most lessen the demand on maritime forces.

Ultimately, the goal of the VULTURE system team is to recommend a satisfactory system that can meet the schedule and budget constraints and will be developed and employed by those charged with the task of OCONUS OPLAT defense. Additionally, the goal is also to provide for future growth of capability through upgrades and incremental technology insertions. The initial efforts included:

- Evaluating/researching known systems
- Assessing unconventional/unique, unproven solutions
- Continuous reevaluation of requirements through stakeholder feedback

The first step of this process was to identify components that would perform the functions previously discussed in paragraph J of section III. Multiple components were identified and analyzed in order to compare each other to determine the best solution. Finally, the relative cost of these alternatives was evaluated to assess which configuration

provided the most performance with least cost. The details of this process and methodology will be discussed in further sections.

1. Mapping Components from Functions

The mapping of functions to components was first identified in Table 8. They are presented in hierarchical format beginning with the top-level VUTURE system shown in Figure 22 followed by the first-tier and second-tier components in Figure 23 through Figure 25. For example, "Weapons Subsystem" is the first-tier component underneath the VULTURE system, and it is composed of two second-tier components "Lethal" and "Non-lethal". As part of this AoA, various concept alternatives for the first-tier and second-tier components are compared with each other to determine a more optimum solution. Concept alternatives for these components are identified and discussed in paragraph B of this section.

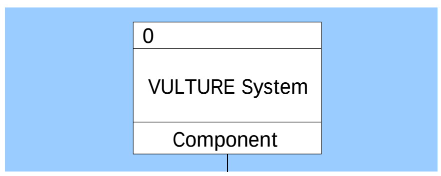


Figure 22: Components Hierarchy

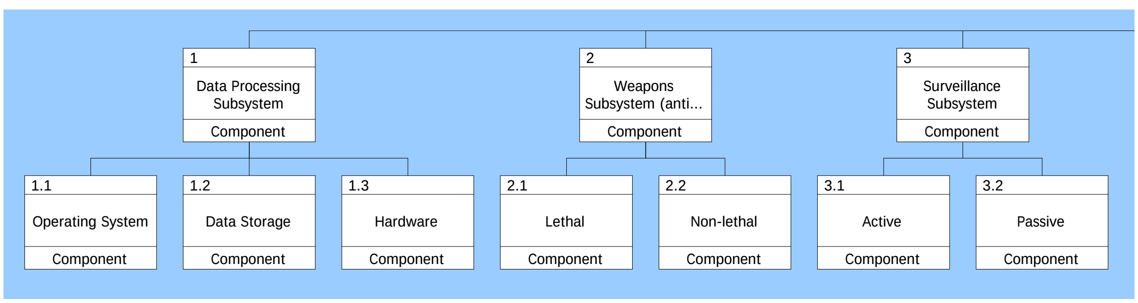


Figure 23: Components Hierarchy breakdown first set

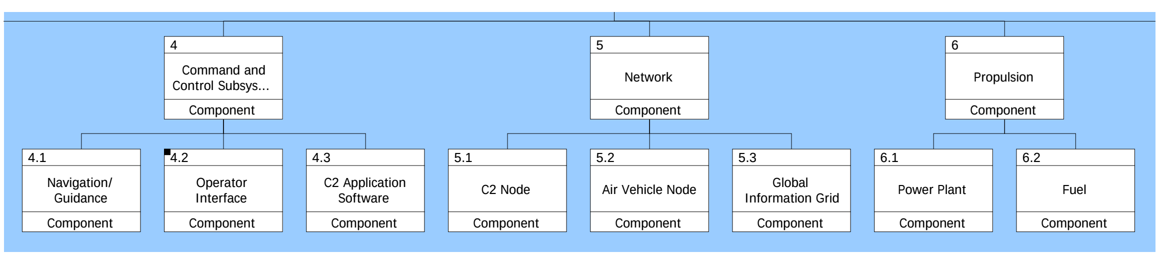


Figure 24: Components Hierarchy breakdown second set

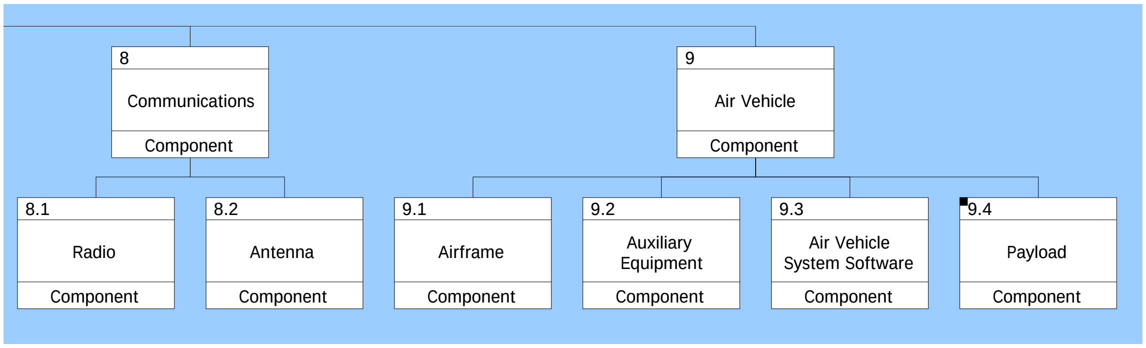


Figure 25: Component Hierarchy breakdown third set

2. Concept Alternatives

The VULTURE system functions can be accomplished through a variety of airborne unmanned systems with a multitude of onboard sensing technology and through different ground stations. Our team focused on the various air vehicle types for this AoA (e.g. rotary wing, fixed wing, and lighter than air). For detailed information regarding sensor packages and surveillance subsystems see *Market Survey for NAVAIR PMA-263 Sea Scout Program TR/07/805/059*, [15]. For a detailed analysis of a UAS ground control station/C^2 system see *Proposed Functional Architecture and Associated Benefits Analysis of a Common Ground Control Station for Unmanned Aircraft Systems* [16].

B. CONCEPT ALTERNATIVES AND EVALUATION IN TERMS OF SYSTEM MOES

Table 9 shows the MOEs which were initially identified in Figure 6 (e.g. QFD 1) along with an associated metric. Our AoA assigns these MOEs to the various first-tier and second-tier components as shown in Figure 26 and Figure 27, form components column and sub-component column, respectively. Next, various concept alternatives were listed for these MOEs. For example the “Data Processing Subsystem” will be formed by the sub-components of “operating system” and “data storage”. The concept alternatives for the “operating system” sub-component are Windows, Unix, and Solaris. Color coding was used to signify the effectiveness of these alternative concepts in relation to the MOE. Green symbolizes highly effective, yellow symbolizes moderately effective, and red symbolizes least effective options relative to each other. This ranking was assigned using inputs from SME feedback.

Table 9: Measures of Effectiveness

TITLE	METRIC
Positive ID	Probability of identification, %
Minimize threat response time	Time to intercept, minutes
Minimize Manpower Footprint	Man-Hours required, hours
Maximize threat deterrence	OPLAT uptime, hours
Transmit Track Location	Data rate, Mb/sec
Transmit Track Speed	Data rate, Mb/sec
Transmit Track ID	Data rate, Mb/sec
Long Range Target Detection	Probability of detection, %
Short Range Target Detection	Probability of detection, %
Track Multiple Targets	Count, number
Launch Weapon on/near target	Probability of kill, %
Endurance	Flight-hours, hours
Launch/Recovery Time	Time to launch/recover, minutes
Survivable	Probability of kill, %
Reliable	MTBF, hours
Available	Availability, %
Physical size	Logistics footprint, square-feet
Weight	Mass, pounds
Interoperable	Net ready, %

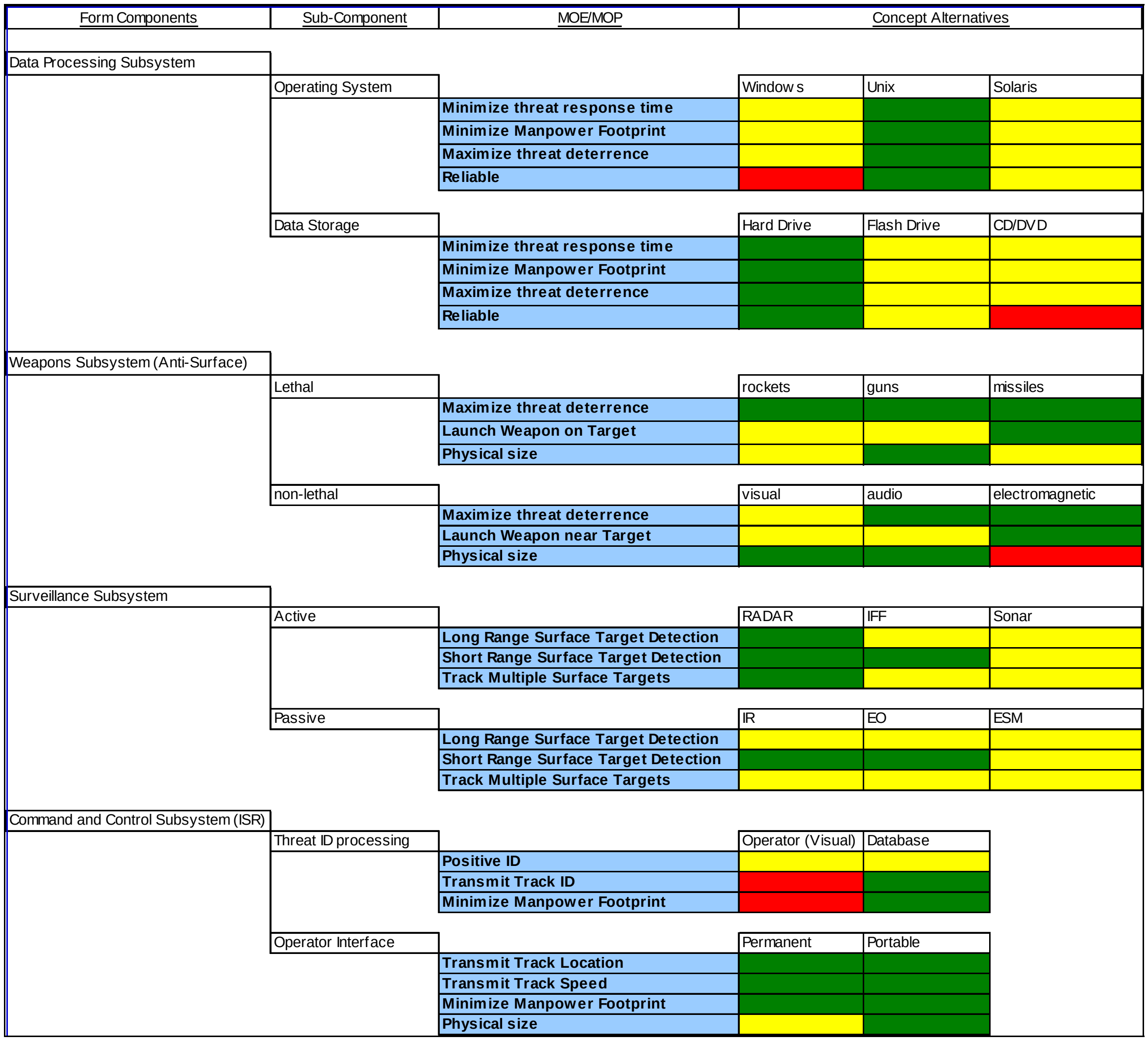


Figure 26: Concept Alternatives Analyzed against MOE

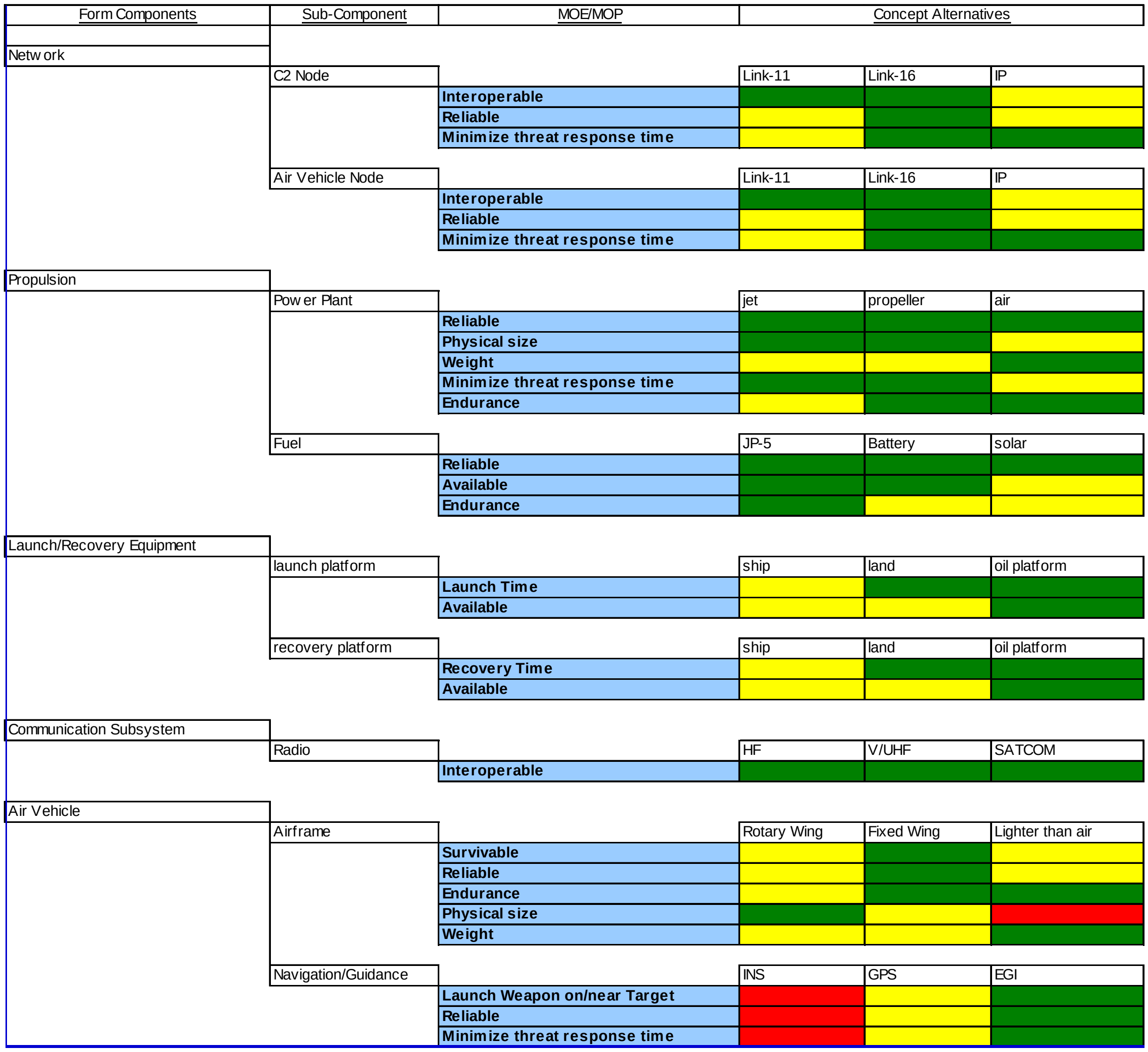


Figure 27: Concept Alternatives Analyzed against MOE (continued)

The concept alternatives in Figure 26 and Figure 27 are by no means an exhaustive listing. They signify common solutions that are extensively used throughout commercial and military systems. These concept alternatives are further consolidated into final rating as seen in Figure 28. Additional color coding was used to signify mixtures of green, yellow, and red in the original assessment. For example, the "Propulsion/Powerplant/Air" concept alternative in Figure 27 had green and yellow ratings. This averaged out to a 'light' green rating in Figure 28. In addition, the "Weapons Subsystem/Non-Lethal/Electromagnetic" concept alternative had green and red ratings which averaged into a light orange color rating. This methodology for using color coding to differentiate various concept alternatives will be

utilized extensively in the morphological matrix which will be discussed in the next paragraph.

Form Components	Sub-Component	Concept Alternatives		
Data Processing Subsystem				
	Operating System	Windows	Unix	Solaris
	Data Storage	Hard Drive	Flash Drive	CD/DVD
Weapons Subsystem (Anti-Surface)				
	Lethal	rockets	guns	missiles
	non-lethal	visual	audio	electromagnetic
Surveillance Subsystem				
	Active	RADAR	IFF	Sonar
	Passive	IR	EO	ESM
Command and Control Subsystem				
	Threat ID processing	Operator (Visual)	Database	
	Operator Interface	Permanent	Portable	
Network				
	C2 Node	Link-11	Link-16	IP
	Air Vehicle Node	Link-11	Link-16	IP
Propulsion				
	Power Plant	jet	propeller	air
	Fuel	JP-5	Battery	solar
Launch/Recovery Equipment				
	launch platform	ship	land	oil platform
	recovery platform	ship	land	oil platform
Communication Subsystem				
	Radio	HF	V/UHF	SATCOM
Air Vehicle				
	Airframe	Rotary Wing	Fixed Wing	Lighter than air
	Navigation/Guidance	INS	GPS	EGI

Figure 28: Consolidated MOE Analysis of Concepts

C. MORPHOLOGICAL MATRIX

Figure 28 was utilized in building a morphological matrix. The morphological matrix was generated in order to ensure that all possible concept alternatives were taken into consideration and that the final configuration of the VULTURE system was maximized for effectiveness.

The weapons, surveillance, propulsion, launch and recovery equipment, and air vehicle systems were all included in the morphological matrix. However, the data processing, C^2, network, and communication systems were not included in the morphological

matrix because the preferred solution was obvious based upon Figure 26, Figure 27, and Figure 28. The best solution for data processing was UNIX and hard drive; for C^2 it was database and portable; for network it was Link-16; and finally communication was high frequency, very/ultra high frequency, and satellite communication.

The final morphological matrix indicated all of the possible combinations of sub-components and produced over 39,000 concept alternatives. The complete morphological matrix is too voluminous for this report but Appendix E contains screenshots of various sections of the matrix.

Table 10 outlines 16 concept alternatives that are thought to best satisfy the measures of effectiveness. The top 2 alternatives for fixed wing, rotary wing and lighter than air UAS platform types are indicated in Table 10.

1. Overall Rating

From Table 10, configurations #1 and #2 are the best "Fixed Wing" vehicles. The best "Rotary Wing" vehicles are configuration #3 and #4. Finally, the best "Lighter than Air" configurations are #5 and #6. These top six configurations will be further assessed for risk in the next section. Ten additional alternatives that were thought to have some value were also included to facilitate a more complete performance rating and cost rating.

Overall, the most significant grouping of concept alternatives is the "Rotary Wing" airframe type. "Fixed Wing" vehicles have the next best rating followed by "Lighter than Air". A significant result is that the best "Fixed Wing" configurations use "Propellers" as the "Power Plant". Obviously, this configuration is important in order for all vehicles to be launched and recovered aboard the OPLAT.

Another interesting aspect of this analysis shows the "Battery" fuel source degrades the overall performance of any airframe that uses it. Obviously, no "Jet" power plant would use the "Battery" as a fuel source; however, a "Propeller" driven "Fixed Wing" could. These interrelationships appear rational.

In conclusion, the morphological matrix process can produce rationale results while based upon subjective assignment of values by experienced VULTURE team members and feedback from SMEs.

Table 10: Top Concept Configurations

	Data Processing		Weapons		Surveillance		Command and Control		Network	Propulsion		Launch/Recovery Equipment		Air Vehicle		
	OS	Storage	Non-Lethal	Lethal	Active	Passive	Threat ID Processing	Operator Interface		Power Plant	Fuel	Launch	Recovery	Airframe	Navigation/ Guidance	
1	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI	Top FW
2	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI	
3	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Rotary Wing	EGI	Top RW
4	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Rotary Wing	EGI	
5	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI	Top Lighter Than Air
6	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI	
7	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Jet	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI	FW
8	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Fixed Wing	EGI	
9	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Jet	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI	
10	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Fixed Wing	EGI	
11	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Rotary Wing	EGI	RW
12	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Rotary Wing	EGI	
13	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI	Lighter Than Air
14	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Air	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI	
15	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI	
16	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Air	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI	

2. Performance Rating

Table 11 contains the performance assessment of the 16 configurations taken from the morphological matrix. The colors (red, yellow, green) were assigned to each "Sub-component" based upon how well the system components would achieve the MOEs. Each component type was rated relative to each other. These ratings were given based on the VULTURE team experience, feedback from SMEs, as well as interaction with users of similar systems and users of the individual components.

For example, concept alternatives #1 and #2 in Table 11 are fixed wing aircraft using propeller propulsion systems. Their effectiveness for deploying an "Audio" weapon system to achieve the MOE of "Threat Deterrence" is less than what could be accomplished by a rotary wing platform. Therefore, "Audio" was colored red for fixed with but green for rotary wing. Furthermore, fixed wing aircraft would have a moderate level (e.g. yellow) of performance recovering aboard an OPLAT since the OPLAT has limited surface space for landing. Yet, all rotary wing airframes have good level (e.g. green) of performance for both recovery and launch from the OPLAT since they move vertically requiring minimal space.

The middle portion of Table 11 simply assigned numerical values to the colors. A higher value means better performance; therefore, green is 3, yellow is 2, and red is 1.

The last portion of Table 11 includes a weighting scheme that is intended to depict how important each component is to at overall performance of the system. For instance a sensor of any kind (active or passive) is more important than a weapon since the weapon cannot be used if a threat target cannot be identified, so it is weighted higher. The weight for each component was multiplied by the numerical value assigned to it in the middle portion and the resulting products were summed for each concept alternative and listed in the last column. These numbers will be used later to develop the cost vs. performance plot.

Further refinement of these numerical ratings is recommended for follow-on investigation. Specific performance levels should be investigated and documented using the House of Quality process discussed in chapter 3 of Blanchard & Fabrycky [5] along with the QFD 2 weightings. For example, the "Weapons Subsystem" can be further decomposed into components that are either already in production or development. Furthermore, specific metrics of importance are listed for guidance:

- Weight

- Cost
- Effective range
- Firing rate
- Types of ordnance
- Accuracy
- Sighting controls

Table 11: Performance Ratings

	Data Processing		Weapons		Surveillance		Command and Control		Network	Propulsion		Launch/ Recovery Equipment		Air Vehicle	
Concept Alternative	OS (AV & C2)	Storage (AV & C2)	Non-Lethal (AV)	Lethal (AV)	Active (C2)	Passive (AV)	Threat ID Processing (C2)	Operator Interface (C2)	(AV and C2)	Power Plant (AV)	Fuel (AV)	Launch (AV)	Recovery (AV)	Airframe (AV)	Navigation/Guidance (AV)
1	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
2	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
3	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Rotary Wing	EGI
4	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Rotary Wing	EGI
5	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
6	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
7	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Jet	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
8	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Fixed Wing	EGI
9	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Jet	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
10	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Fixed Wing	EGI
11	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Rotary Wing	EGI
12	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Rotary Wing	EGI
13	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
14	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Air	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
15	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
16	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Air	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI

Concept Alternative	OS (AV & C2)	Storage (AV & C2)	Non-Lethal (AV)	Lethal (AV)	Active (C2)	Passive (AV)	Threat ID Processing (C2)	Operator Interface (C2)	(AV and C2)	Power Plant (AV)	Fuel (AV)	Launch (AV)	Recovery (AV)	Airframe (AV)	Navigation/Guidance (AV)
1	3	3	1	3	3	3	3	3	3	3	3	3	2	3	3
2	3	3	1	3	3	3	3	3	3	3	3	3	2	3	3
3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3
4	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3
5	2	2	3	2	3	2	3	3	2	3	3	3	3	2	3
6	2	2	3	1	3	2	3	3	2	3	3	3	3	2	3
7	3	3	1	3	3	3	3	3	3	2	3	3	2	3	3
8	3	3	1	3	3	3	3	3	3	3	1	3	2	3	3
9	3	3	1	3	3	3	3	3	3	2	3	3	2	3	3
10	3	3	1	3	3	3	3	3	3	3	1	3	2	3	3
11	3	3	3	3	3	3	3	3	3	3	2	3	3	2	3
12	3	3	3	3	3	3	3	3	3	3	2	3	3	2	3
13	2	2	3	2	3	2	3	3	2	3	3	3	3	2	3
14	2	2	3	2	3	2	3	3	2	2	3	3	3	2	3
15	2	2	3	1	3	2	3	3	2	3	3	3	3	2	3
16	2	2	3	1	3	2	3	3	2	2	3	3	3	2	3

	OS (AV & C2)	Storage (AV & C2)	Non-Lethal (AV)	Lethal (AV)	Active (C2)	Passive (AV)	Threat ID Processing (C2)	Operator Interface (C2)	(AV and C2)	Power Plant (AV)	Fuel (AV)	Launch (AV)	Recovery (AV)	Airframe (AV)	Navigation/Guidance (AV)	
Weights	**3**	**1**	**3**	**2**	**4**	**4**	**5**	**3**	**2**	**3**	**3**	**3**	**2**	**4**	**2**	
Concept Alternative																Totals
1	9	3	3	6	12	12	15	9	6	9	9	9	4	12	6	124
2	9	3	3	6	12	12	15	9	6	9	9	9	4	12	6	124
3	9	3	9	6	12	12	15	9	6	9	9	9	6	8	6	128
4	9	3	9	6	12	12	15	9	6	9	9	9	6	8	6	128
5	6	2	9	4	12	8	15	9	4	9	9	9	6	8	6	116
6	6	2	9	2	12	8	15	9	4	9	9	9	6	8	6	114
7	9	3	3	6	12	12	15	9	6	6	9	9	4	12	6	121
8	9	3	3	6	12	12	15	9	6	9	3	9	4	12	6	118
9	9	3	3	6	12	12	15	9	6	6	9	9	4	12	6	121
10	9	3	3	6	12	12	15	9	6	9	3	9	4	12	6	118
11	9	3	9	6	12	12	15	9	6	9	6	9	6	8	6	125
12	9	3	9	6	12	12	15	9	6	9	6	9	6	8	6	125
13	6	2	9	4	12	8	15	9	4	9	9	9	6	8	6	116
14	6	2	9	4	12	8	15	9	4	6	9	9	6	8	6	113
15	6	2	9	2	12	8	15	9	4	9	9	9	6	8	6	114
16	6	2	9	2	12	8	15	9	4	6	9	9	6	8	6	111

3. Relative Cost Rating

The 16 configurations shown in Table 10 were also subjectively assessed for cost, and the results are depicted in Table 12. Again, the colors red, yellow, and green were assigned based upon the relative cost of the component type in relationship to each other. In this case green is again better than yellow which is better than red.

A limitation to this cost rating is that actual costs were not utilized, as the team used only subjective comparisons. These ratings were given based on the VULTURE team experience, feedback from SMEs, as well as interaction with users of similar systems and users of the individual components. Since actual costs were not specifically identified, no dollar value or estimated fiscal year projection can be performed using this analysis methodology.

One of the key aspects to assigning a cost rating is complexity. For example, the column "Airframe" in **Error! Reference source not found.** shows the "Fixed Wing" as yellow, "Rotary Wing" as red, and "Lighter than Air" as green. In relationship to each other, the "Lighter than Air" airframe is less complex than the other two types because it has the least number of moving parts. Next complex airframe is the "Fixed Wing" since it creates lift on its wings vice using rotors and gearbox subsystems like the "Rotary Wing" airframe does. Finally, the "Rotary Wing" airframe requires complicated flight controls along with strong, lightweight, and expensive materials like titanium in the rotors to survive the high stress and vibratory environment.

Another perspective for cost rating is the level of difficulty integrating systems onboard these airframes. For example, "Missiles" are more complicated to integrate on all the airframes than "Guns" because they require targeting information, launch commands, and self-contained guidance systems. In addition, both "Missiles" and "Guns" are more difficult to integrate on a "Lighter than Air" airframe because of their explosive forces on its buoyancy properties; e.g., every action has an opposite and equal reaction.

This process was similar to the performance rating, however, a lower cost is more desirable so when assigning numerical values in the middle section of Table 12, green is 1, yellow is 2, and red is 3.

The last portion of Table 12 includes a weighting scheme that is intended to depict how price tolerant each component is to at overall cost of the system. For instance an air

vehicle type selection is a requirement for the system to exist. Since the air vehicle component is likely going to be the most expensive portion of the system, it is weighted as a 1 to indicate that even though it is expensive that is accepted and should not affect the cost analysis in any extreme way. By contrast, the method of recovery is not as relevant to the overall mission and therefore is rated a 6 to indicate that an extreme expense in this area would not be recommended. The weight for each component was multiplied by the numerical value assigned to it in the middle portion and the resulting products were summed for each concept alternative and listed in the last column. These numbers will be used later to develop the cost vs. performance plot.

Further investigation of actual cost values for these configurations is recommended. These data should be included with the performance values discussed previously.

Table 12: Cost Ratings

	Data Processing		Weapons		Surveillance		Command and Control		Network	Propulsion		Launch/ Recovery Equipment		Air Vehicle	
Concept Alternative	OS (AV & C2)	Storage (AV & C2)	Non-Lethal (AV)	Lethal (AV)	Active (C2)	Passive (AV)	Threat ID Processing (C2)	Operator Interface (C2)	(AV and C2)	Power Plant (AV)	Fuel (AV)	Launch (AV)	Recovery (AV)	Airframe (AV)	Navigation/Guidance (AV)
1	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
2	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
3	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Rotary Wing	EGI
4	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	JP-5	Oil Platform	Oil Platform	Rotary Wing	EGI
5	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
6	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
7	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Jet	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
8	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Fixed Wing	EGI
9	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Jet	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
10	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Fixed Wing	EGI
11	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Rotary Wing	EGI
12	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Rotary Wing	EGI
13	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
14	UNIX	Hard Drive	Audio	GUNS	RADAR	EO/IR	Database	Portable	Link-16	Air	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
15	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Propeller	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI
16	UNIX	Hard Drive	Audio	Missiles	RADAR	EO/IR	Database	Portable	Link-16	Air	Battery	Oil Platform	Oil Platform	Lighter than Air	EGI

Concept Alternative	OS (AV & C2)	Storage (AV & C2)	Non-Lethal (AV)	Lethal (AV)	Active (C2)	Passive (AV)	Threat ID Processing (C2)	Operator Interface (C2)	(AV and C2)	Power Plant (AV)	Fuel (AV)	Launch (AV)	Recovery (AV)	Airframe (AV)	Navigation/Guidance (AV)
1	1	1	3	1	1	2	1	1	1	2	1	2	2	2	1
2	1	1	3	2	1	2	1	1	1	2	1	2	2	2	1
3	1	1	2	1	1	1	1	1	1	2	1	1	1	3	1
4	1	1	2	2	1	1	1	1	1	2	1	1	1	3	1
5	2	2	1	3	1	3	1	1	3	2	1	1	1	1	1
6	2	2	1	3	1	3	1	1	3	2	1	1	1	1	1
7	1	1	3	1	1	2	1	1	1	3	1	2	2	2	1
8	1	1	3	1	1	2	1	1	1	2	3	2	2	2	1
9	1	1	3	2	1	2	1	1	1	3	1	2	2	2	1
10	1	1	3	2	1	2	1	1	1	2	3	2	2	2	1
11	1	1	2	1	1	1	1	1	1	2	3	1	1	3	1
12	1	1	2	2	1	1	1	1	1	2	3	1	1	3	1
13	2	2	1	3	1	3	1	1	3	2	1	1	1	1	1
14	2	2	1	3	1	3	1	1	3	1	1	1	1	1	1
15	2	2	1	3	1	3	1	1	3	2	1	1	1	1	1
16	2	2	1	3	1	3	1	1	3	1	1	1	1	1	1

	OS (AV & C2)	Storage (AV & C2)	Non-Lethal (AV)	Lethal (AV)	Active (C2)	Passive (AV)	Threat ID Processing (C2)	Operator Interface (C2)	(AV and C2)	Power Plant (AV)	Fuel (AV)	Launch (AV)	Recovery (AV)	Airframe (AV)	Navigation/Guidance (AV)	
Weights	4	4	3	2	1	3	1	3	4	3	2	3	5	1	4	
Concept Alternative																Totals
1	4	4	9	2	1	6	1	3	4	6	2	6	10	2	4	64
2	4	4	9	4	1	6	1	3	4	6	2	6	10	2	4	66
3	4	4	6	2	1	3	1	3	4	6	2	3	5	3	4	51
4	4	4	6	4	1	3	1	3	4	6	2	3	5	3	4	53
5	8	8	3	6	1	9	1	3	12	6	2	3	5	1	4	72
6	8	8	3	6	1	9	1	3	12	6	2	3	5	1	4	72
7	4	4	9	2	1	6	1	3	4	9	2	6	10	2	4	67
8	4	4	9	2	1	6	1	3	4	6	6	6	10	2	4	68
9	4	4	9	4	1	6	1	3	4	9	2	6	10	2	4	69
10	4	4	9	4	1	6	1	3	4	6	6	6	10	2	4	70
11	4	4	6	2	1	3	1	3	4	6	6	3	5	3	4	55
12	4	4	6	4	1	3	1	3	4	6	6	3	5	3	4	57
13	8	8	3	6	1	9	1	3	12	6	2	3	5	1	4	72
14	8	8	3	6	1	9	1	3	12	3	2	3	5	1	4	69
15	8	8	3	6	1	9	1	3	12	6	2	3	5	1	4	72
16	8	8	3	6	1	9	1	3	12	3	2	3	5	1	4	69

D. RISK ANALYSIS

1. Overview

From Table 10, concept alternatives 1 thru 6 have been identified as systems that could potentially satisfy the needs of the stakeholders. As these were the top two alternatives per air vehicle type, the risk analysis was limited to these 6 (out of the available 16). The risk analysis was performed order to determine the feasibility of designing, producing, and fielding each of the 6 concept alternatives successfully.

Three system level risks were identified and scored for each of the six concepts. The bulk of the design effort in the VULTURE program is envisioned to be related to the integration of multiple technologies into a single system. Historical precedence has shown that integration is often a high risk area. Therefore, all three system level risks is related to system integration.

Risk 1 – Integration of Lethal Weapons: Risk that the specified weapon (guns or missiles) cannot be successfully integrated onto the specified airframe (fixed wing, rotary wing, or lighter than air).

Risk 2 – Integration of Non-lethal Weapons: Risk that the non-lethal weapon (a focused noise device) cannot be successfully integrated onto the specified airframe (fixed wing, rotary wing, or lighter than air).

Risk 3 – Integration of Airframe Type: Risk that the specified airframe (fixed wing, rotary wing, or lighter than air) cannot be successfully integrated with operations based from the OPLAT.

For each concept alternative, each of the three risks was evaluated for the probability of the risk being realized and for the consequence of the risk being realized. Furthermore, the consequence was scored in two ways; (1) technical consequence of degraded system performance, and (2) cost and schedule consequence that would impact the program. At this early stage of project definition, it did not make sense to separate cost risk from schedule risk since the two will almost certainly be directly related.

The method used for scoring the program risks was the standard set by the Naval Air Systems Command (NAVAIR) Risk Management Policy. Risk is comprised of two components; likelihood and consequence. Table 13 shows the likelihood criteria used to select the level of risk.

Table 13: Likelihood Criteria

Level	Likelihood	Probability of Occurrence
1	Not Likely	~10%
2	Low Likelihood	~30%
3	Likely	~50%
4	Highly Likely	~70%
5	Near Certainty	~90%

The consequence criteria are shown in Table 14. This table details the various levels of risk and the resultant cost from that risk. Now that the morphological matrix narrowed the configurations down to six concepts alternatives as shown in Table 15. The team scored them for risk as contained in Table 16. A detailed description of the basis for each of these scores is located in the Risk Factor Calculations section.

Table 14: Consequence Criteria

Level	Technical Performance	Schedule	Cost
1	Minimal or no consequence to technical performance	Minimal or no impact	Minimal or no impact
2	Minor reduction in technical performance or supportability, can be tolerated with little or no impact on program	Able to meet key dates **Slip < 1 month**	Budget increase or unit production cost increases. **< 1% of Budget**
3	Moderate reduction in technical performance or supportability with limited impact on program objectives	Minor schedule slip. Able to meet key milestones with no schedule float. **Slip < 2 months** **Sub-system slip > 1 month plus available float.**	Budget increase or unit production cost increase **< 5% of Budget**
4	Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success	Program critical path affected. **Slip < 6 months**	Budget increase or unit production cost increase < **10% of Budget**
5	Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success	Cannot meet key program milestones. **Slip > 6 months**	Exceeds APB threshold **>10% of Budget**

Table 15: Concept Configurations

Variant	Airframe	Lethal Weapon	Non-lethal weapon
Concept 1	Fixed Wing	Guns	Focused Noise Device
Concept 2	Fixed Wing	Missiles	Focused Noise Device
Concept 3	Rotary Wing	Guns	Focused Noise Device
Concept 4	Rotary Wing	Missiles	Focused Noise Device
Concept 5	Lighter than Air	Guns	Focused Noise Device
Concept 6	Lighter than Air	Missiles	Focused Noise Device

Table 16: Risk Score of Concepts

	Risk 1			Risk 2			Risk 3		
Variant	Likelihood	Tech Cons	Cost/Sched Cons	Likelihood	Tech Cons.	Cost/Sched Cons.	Likelihood	Tech Cons.	Cost/Sched Cons
Concept 1	2	3	4	3	3	3	2	4	4
Concept 2	3	3	4	3	3	3	2	4	4
Concept 3	3	3	4	2	3	3	1	4	3
Concept 4	3	3	4	2	3	3	1	4	3
Concept 5	4	3	4	2	3	3	2	4	2
Concept 6	4	3	4	2	3	3	2	4	2

Tech-Technical
Cons - Consequence
Sched - Schedule

To assess the relative risk of each concept the Risk Factor method was used. For each concept the Risk Factor was calculated using the formulas shown in equations 1, 2, and 3. For the consequence value, the greater of the technical consequence and the cost/schedule consequence values was used. The detailed calculations for the risk factor ratings are shown in Appendix F.

$$RiskFactor = 1 - (1 - P_f)(1 - C_f) \qquad \textbf{Equation 1}$$

$$P_f = \sum (\alpha * \Pr obability) \qquad \textbf{Equation 2}$$

$$C_f = \sum (\alpha * Consequence) \qquad \textbf{Equation 3}$$

Table 17: Individual Concepts Risk Factor

Variant	Risk Factor
Concept 1	76%
Concept 2	79%
Concept 3	74%
Concept 4	74%
Concept 5	79%
Concept 6	79%

The risk factors are all within 5% of each other, indicating that there is not a large variation in the amount of risk assumed by choosing any particular concept as opposed to another. Although the variation is relatively small there is a trend showing that the "Rotary Wing" airframe may have some advantages over the other choices when it comes to the risk of development and integration.

2. Detailed Risk Analysis

The Risk Cubes shown in Figure 29 display the three risk ratings for each of the six concepts. The cubes are followed by a description of each specific risk score and the reasoning behind it.

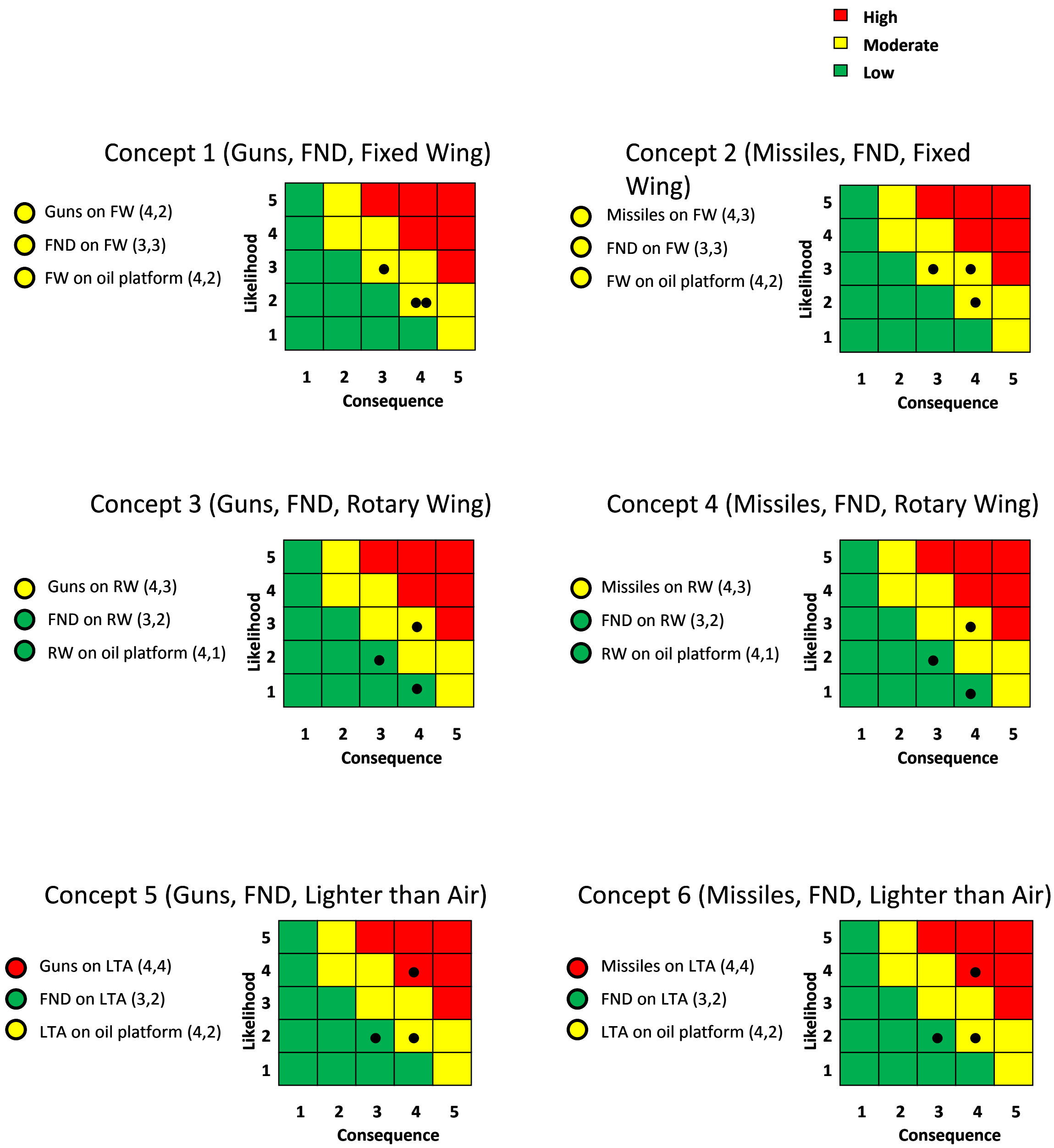


Figure 29: Risk Cubes for the Various Platforms and Configurations

Concept 1

<u>Risk #1 – Guns on Fixed Wing</u>

Cost and Schedule: 4 – If the weapon cannot be successfully integrated a large schedule delay as well as large cost will be incurred as resolving integration issues will

require technical teams from various disciplines (airframe, weapons, sensors, flight controls) and will likely require full scale testing.

Technical: 3 – If the guns cannot perform up to the expected potential (accuracy, range, number of rounds, lethality, etc) due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the required mission.

Probability: 2 – There has not been much work specific to integrating guns onto UASs, however other weapons have been integrated successfully. The guns would be a mature technology and would likely be optically guided using the onboard EO/IR system. The EO/IR system would also be mature technologies, although the integration of it all together does pose some risk.

Risk #2 – Focused Noise Device (FND) on Fixed Wing

Cost and Schedule: 3 – If the FND cannot be implemented successfully a moderate amount of rework will likely be required which will add some additional cost and schedule.

Technical: 3 – If the FND cannot perform up to the expected potential due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the non-lethal mission.

Probability: 3 – FND are typically used from stationary platforms. Integrating one onto a fixed wing UAS will be moderately challenging due to the requirement of keeping the noise beam pointed at the threat for an extended period of time. Sensors, flight controls, and the FND will all need to be integrated together.

Risk #3 – Fixed Wing on an Oil Platform

Cost and Schedule: 4 – If the UAS is unable to take off or land from the OPLAT an alternative would need to be developed. Water based UAS have been designed so it would not be a brand new technology but would still pose some challenges which would increase program cost and schedule.

Technical: 4 – If the UAS cannot land directly on the OPLAT it will need to be recovered from the water which will cause a significant impact to the time required for operations as well as create new requirements for the system to survive the environmental effects of a water landing.

Probability: 2 – Fixed wing UAS with many different take off and landing methods have been developed for other applications that could be used or modified for an OPLAT.

Concept 2

Risk #1 – Missiles on Fixed Wing

Cost and Schedule: 4 – If the weapon cannot be successfully integrated a large schedule delay as well as large cost will be incurred as resolving integration issues will require technical teams from various disciplines (airframe, weapons, sensors, flight controls) and will likely require full scale testing.

Technical: 3 – If the missiles cannot perform up to the expected potential (accuracy, range, number of rounds, lethality, etc) due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the required mission.

Probability: 3 – Missiles have been implemented on Fixed Wing UAS before but the integration of this specific weapon, UAS, and sensors likely will have some technical challenges.

Risk #2 – Focused Noise Device on Fixed Wing

Cost and Schedule: 3 – If the FND cannot be implemented successfully a moderate amount of rework will likely be required which will add some additional cost and schedule.

Technical: 3 – If the FND cannot perform up to the expected potential due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the non-lethal mission.

Probability: 3 – FND are typically used from stationary platforms. Integrating one onto a fixed wing UAS will be moderately challenging due to the requirement of keeping the noise beam pointed at the threat for an extended period of time. Sensors, flight controls, and the FND will all need to be integrated together.

Risk #3 – Fixed Wing on an Oil Platform

Cost and Schedule: 4 – If the UAS is unable to take off or land from the OPLAT an alternative would need to be developed. Water based UAS have been designed so it would not be a brand new technology but would still pose some challenges which would increase program cost and schedule.

Technical: 4 – If the UAS cannot land directly on the OPLAT it will need to be recovered from the water which will cause a significant impact to the time required for operations as well as create new requirements for the system to survive the environmental effects of a water landing.

Probability: 2 – Fixed wing UAS with many different take off and landing methods have been developed for other applications that could be used or modified for an OPLAT.

Concept 3

Risk #1 – Guns on Rotary Wing

Cost and Schedule: 4 – If the weapon cannot be successfully integrated a large schedule delay as well as large cost will be incurred as resolving integration issues will require technical teams from various disciplines (airframe, weapons, sensors, flight controls) and will likely require full scale testing.

Technical: 3 – If the guns cannot perform up to the expected potential (accuracy, range, number of rounds, lethality, etc) due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the required mission.

Probability: 3 – The task of integrating guns onto a rotary wing UAS will not be too much different from a fixed wing UAS, however not as much work has been done in this area so unexpected technical challenges are likely.

Risk #2 – Focused Noise Device on Rotary Wing

Cost and Schedule: 3 – If the FND cannot be implemented successfully a moderate amount of rework will likely be required which will add some additional cost and schedule.

Technical: 3 – If the FND cannot perform up to the expected potential due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the non-lethal mission.

Probability: 2 – FND are typically used from stationary platforms. Integrating one onto a rotary wing UAS will be more challenging due to the requirement of keeping the noise beam pointed at the threat for an extended period of time as well as the need to integrate the FND closely with sensors and flight controls.

Risk #3 – Rotary Wing on Oil Platform

Cost and Schedule: 3 – If issues arise when integrating the rotary wing UAS with the OPLAT they will likely require a moderate level of engineering and design changes to expand the landing area or improve the flight control software.

Technical: 4 – If the UAS cannot take off and land from the OPLAT any alternative method developed would likely have a significant impact on operations.

Probability: 1 – Rotary wing UAS have been fielded with the capability to take off and land from areas similar in size to OPLATs.

Concept 4

Risk #1 – Missiles on Rotary Wing

Cost and Schedule: 4 – If the weapon cannot be successfully integrated a large schedule delay as well as large cost will be incurred as resolving integration issues will

require technical teams from various disciplines (airframe, weapons, sensors, flight controls) and will likely require full scale testing.

Technical: 3 – If the guns cannot perform up to the expected potential (accuracy, range, number of rounds, lethality, etc) due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the required mission.

Probability: 3 – The task of integrating missiles onto a rotary wing UAS will not be too much different from a fixed wing UAS, however not as much work has been done in this area so unexpected technical challenges are likely.

<u>Risk #2 – Focused Noise Device on Rotary Wing</u>

Cost and Schedule: 3 – If the FND cannot be implemented successfully a moderate amount of rework will likely be required which will add some additional cost and schedule.

Technical: 3 – If the FND cannot perform up to the expected potential due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the non-lethal mission.

Probability: 2 – FND are typically used from stationary platforms. Integrating one onto a rotary wing UAS will be more challenging due to the requirement of keeping the noise beam pointed at the threat for an extended period of time as well as the need to integrate the FND closely with sensors and flight controls.

<u>Risk #3 – Rotary Wing on Oil Platform</u>

Cost and Schedule: 3 – If issues arise when integrating the rotary wing UAS with the OPLAT they will likely require a moderate level of engineering and design changes to expand the landing area or improve the flight control software.

Technical: 4 – If the UAS cannot take off and land from the OPLAT any alternative method developed would likely have a significant impact on operations.

Probability: 1 – Rotary wing UAS have been fielded with the capability to take off and land from areas similar in size to OPLATs.

Concept 5

Risk #1 – Guns on Lighter than Air (LTA)

Cost and Schedule: 4 – If the weapon cannot be successfully integrated a large schedule delay as well as large cost will be incurred as resolving integration issues will require technical teams from various disciplines (airframe, weapons, sensors, flight controls) and will likely require full scale testing.

Technical: 3 – If the guns cannot perform up to the expected potential (accuracy, range, number of rounds, lethality, etc) due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the required mission.

Probability: 4 – LTA aircraft have never been equipped with weapons. Typically an LTA does not have as much payload capability as a FW or RW aircraft of the same physical size. Integration of weapons will likely be a large technically challenge.

Risk #2 – Focused Noise Device (FND) on Lighter than Air

Cost and Schedule: 3 – If the FND cannot be implemented successfully a moderate amount of rework will likely be required which will add some additional cost and schedule.

Technical: 3 – If the FND cannot perform up to the expected potential due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the non-lethal mission.

Probability: 2 – Stationary platforms are the typical platform to incorporate a FND. Integrating one onto a Lighter than Air UAS will be more challenging due to the requirement of keeping the noise beam pointed at the threat for an extended period of time as well as the need to integrate the FND closely with sensors and flight controls.

Risk #3 – Lighter than Air on Oil Platform (5,2)

Cost and Schedule: 2 – If issues arise when integrating the Lighter than Air UAS with the OPLAT they will likely require a modest level of engineering and design changes to the landing area or improve the flight control software.

Technical: 4 – If the UAS cannot take off and land from the OPLAT any alternative method developed would likely have a significant impact on operations.

Probability: 2 – LTA aircraft typically have less control than rotary wing aircraft and therefore require a larger area to land. High winds atop a seabased OPLAT will increase the landing challenges.

Concept 6

Risk #1 – Missiles on Lighter than Air

Cost and Schedule: 4 – If the weapon cannot be successfully integrated a large schedule delay as well as large cost will be incurred as resolving integration issues will require technical teams from various disciplines (airframe, weapons, sensors, flight controls) and will likely require full scale testing.

Technical: 3 – If the missiles cannot perform up to the expected potential (accuracy, range, number of rounds, lethality, etc) due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the required mission.

Probability: 4 – LTA aircraft have never been equipped with weapons. Typically an LTA does not have as much payload capability as a FW or RW aircraft of the same physical size. Integration of weapons will likely be a large technically challenge.

Risk #2 – Focused Noise Device on Lighter than Air

Cost and Schedule: 3 – If the FND cannot be implemented successfully a moderate amount of rework will likely be required which will add some additional cost and schedule.

Technical: 3 – If the FND cannot perform up to the expected potential due to integration issues with the platform, there will be a moderate degradation of total system capability when performing the non-lethal mission.

Probability: 2 – FND are typically used from stationary platforms. Integrating one onto a Lighter than Air UAS will be more challenging due to the requirement of keeping the noise beam pointed at the threat for an extended period of time as well as the need to integrate the FND closely with sensors and flight controls.

Risk #3 - Lighter than Air on Oil Platform

Cost and Schedule: 2 – If issues arise when integrating the Lighter than Air UAS with the OPLAT they will likely require a modest level of engineering and design changes to the landing area or improve the flight control software.

Technical: 4 – If the UAS cannot take off and land from the OPLAT any alternative method developed would likely have a significant impact on operations.

Probability: 2 – LTA aircraft typically have less control than rotary wing aircraft and therefore require a larger area to land. High winds atop a sea-based OPLAT will increase the landing challenges.

V. SYNTHESIS

A. BANG VERSUS BUCK

Results from the performance and cost ratings (Tables 11 and 12) were used to develop the cost versus performance graph in Figure 30. Each of the 16 configurations is shown in the legend. Performance levels increase on the ordinate, and cost increases on the abscissa. In order to determine the best "bang for the buck", a line is drawn outward, vertically from the ordinate and then lowered toward the first set of data points as shown in the blue and red lines on Figure 30. The red line in Figure 30 depicts the best "Fixed Wing" solutions, while the blue line depicts the best "Rotary Wing" solutions.

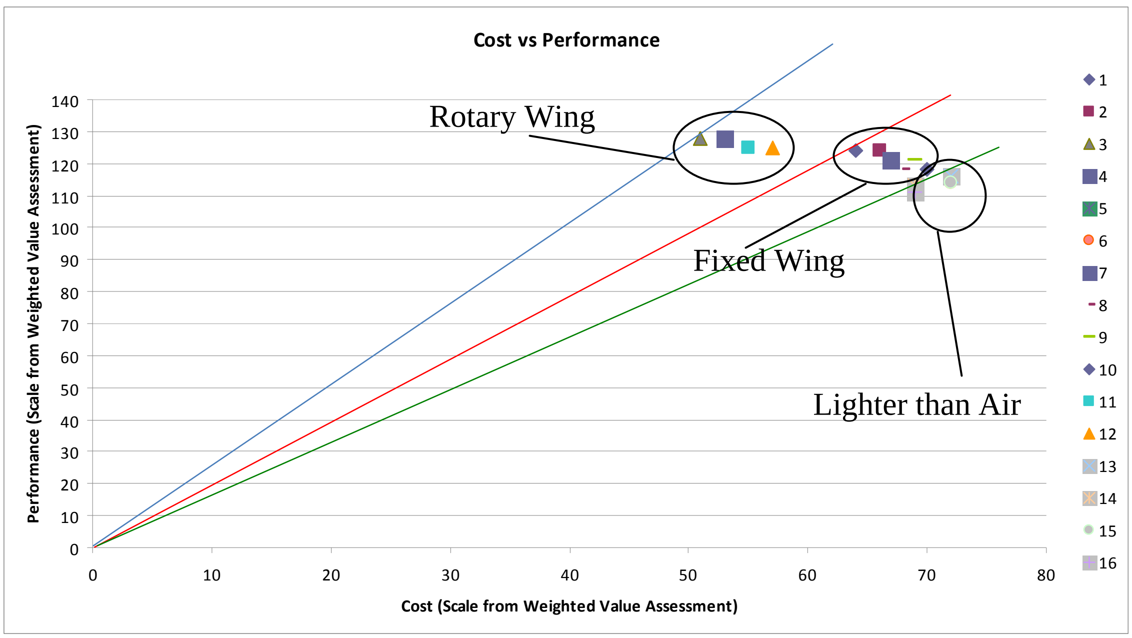


Figure 30: Cost versus Performance

Since the blue line intersects first with the group of data points, the "Rotary Wing" concepts are considered the best suited when considering cost vs. performance to meet the stakeholder's needs. The next best group of concepts is "Fixed Wing" followed by the "Lighter than Air" group. Overall, this cost versus performance analysis shows that Configuration #3 is the best "Rotary Wing" airframe, Configuration #1 is the best

“Fixed Wing” airframe and the “Lighter than Air” options were clustered too close together to determine a clear winner.

B. MODELING AND SIMULATION

1. Approach

The capability needs statement indicates that a primary need is to efficiently and effectively neutralize surface threats to OPLATs. The team’s interactions with stakeholders have also indicated that the ability of the UAS to maintain a persistent on station time is also a priority. Therefore, the intent of the Microsoft Excel based Simulation, developed by our team, was to illustrate the trade-off between efficient and effective neutralization of surface threats and Persistent On-Station time.

The following are baseline assumptions that were necessary to frame the simulation:

- All the target tracks indicated in the simulation have been positively identified as threats (constant bearing, decreasing range to OPLAT) prior to them being acknowledged by the simulation (randomly generated threats with randomized start location and speed). This course and bearing satisfied the simulations minimal ROE.
- All UAS speeds and endurance times were taken from the *Shepard Unmanned Vehicles Handbook* [17].
- If the UAS reaches 0.5 miles of a target it is assumed it will be neutralized, there was no consideration to exhaustion of onboard stores.
- The total simulated time was 24hrs.
- Total simulated threats will not exceed 50 in a 24 hr period (this is likely a very high estimate, but threat saturation was the goal).

The desired outcome from the simulation was to determine:

- How many targets could be neutralized by the UAS.
- When each UAS was no longer available (ran out of gas).

The following UAS types listed in Table 18 were determined suitable for the mission and the ones highlighted yellow were actually simulated.

Table 18: Suitable OPLAT defense UAS models

UAS Name	Type	Status	Max Speed (Knots)	Endurance Speed (Knots)	Endurance Time (Hrs)	Country	Shepard Handbook Page
APID 55	RW	Production	54	32	6	Sweden	8
Shadow 200	FW	Production	123	75	5.5	USA	30
TAG M100	RW	Development	81	66	5.7	USA	65
TAG M65	RW	Development	59	54	4.5	USA	66
Firescout	RW	Production	125	50	6	USA	13
Seascan	FW	Production	63	43	15	USA	29
Sentry	FW	Production	95	70	6	USA	30
Vigilante 502	RW	Production	117	50	7	USA	36
ISIS	FW	Development	104	69.5	24	USA	52
SA-90	LTA	Development	40	40	48	USA	60

There is a mix of production UAS systems as well as developmental UAS systems. The team could only find one Lighter Than Air (LTA) system and it was under development. The results from the OPLAT defense UAS simulation are documented in Table 19.

Table 19: OPLAT defense UAS Simulation results

Shadow 200	TAG M100	Firescout	ISIS	SA-90
A/V Max Speed	A/V Max Speed	A/V Max Speed	A/V Max Speed	A/V Max Speed
123	81	125	104	40
A/V Endurance Speed	A/V Endurance Speed	A/V Endurance Speed	A/V Endurance Speed	A/V Endurance Speed
75	66	50	69.5	40
A/V Endurance Time	A/V Endurance Time	A/V Endurance Time	A/V Endurance Time	A/V Endurance Time
330	342	360	1440	2880
A/V Time Remaining	A/V Time Remaining	A/V Time Remaining	A/V Time Remaining	A/V Time Remaining
-1	-1	-1	-1	0
Sum of all time at max Speed	Sum of all time at max Speed	Sum of all time at max Speed	Sum of all time at max Speed	Sum of all time at max Speed
106	123	91	454	1440
Total time at endurance speed	Total time at endurance speed	Total time at endurance speed	Total time at endurance speed	Total time at endurance speed
157	192	133	761	1440
Am I available?/Time of Not Available	Am I available?/Time of Not Available	Am I available?/Time of Not Available	Am I available?/Time of Not Available	Am I available?/Time of Not Available
No	No	No	No	No
Total Operating Time	Total Operating Time	Total Operating Time	Total Operating Time	Total Operating Time
264	316	225	1216	1440

Note: Input Parameters are highlighted in yellow.

Clarification of the simulation results are tabulated in Table 20. These results were further analyzed.

Table 20: Analysis of results

UAS	Total Operation Time	# of Threats Neutralized per Hour of Operation	# of Threats That Reached OPLAT per Hour of Operation	Total Threats Present During Operation Time	# of Threats Neutralized per 24hrs (assuming 24hr coverage via multiple assets if necessary)	Total Threats Present per 24 hrs
Shadow 200	4.40	2.27	0.23	11	54.55	50
TAG M100	5.27	2.47	0.19	14	59.24	50
Firescout	3.75	2.13	0.27	9	51.20	50
ISIS	20.27	2.02	0.30	47	48.55	50
SA-90	24.00	1.88	0.21	50	45.00	50

Table 20 clearly indicates that the UAS system that is most efficient at neutralizing threats is the TAG M100 Rotary Wing option with nearly 2.5 threats neutralized per hour of operation and only 0.19 targets actually reaching the OPLAT per hour of operation. Conversely the SA-90 LTA option can only neutralize 1.88 threats per hour of operation and the ISIS Fixed Wing option neutralizes 2.02. The ISIS was even worse when considering that 0.30 targets reached the OPLAT per hour of operation. However, this is only in the context of actual operating time. When the options were analyzed with regard to the entire 24 hour simulation period the results are a bit different. The on station time of the LTA was the best (up to 48 hrs) so it stayed airborne for the entire simulation. All the rest of the options ran out of fuel prior to the 24 hour limit. At this point, some interpolation was undertaken to determine that if the other options were available for the 24 hour period (refuel and/or a second same type UAS system was utilized) how good their respective neutralization numbers would be. Using the results of this interpolation it was determined that if the TAG M100 could remain on station for 24 hours (likely via the use of multiple UAS systems) then it could in theory neutralize over 59 randomly occurring threats. This is well over our simulated threat level of 50 per 24 hrs so it is reasonable to think that few if any threats would make it to the OPLATS before being neutralized. The Firescout UAS would also be satisfactory.

2. Limitations

The simulation was set up in such a way that it took just over 30 minutes to produce a single iteration of the program. As such, the results of the simulation are not

statistically significant, but some basic conclusions can be determined as noted above. The ideal solution would be to run the simulation 100 or more times and average the results to foster a deep statistical analysis. Given time constraints this was not possible to produce for the report, but the simulation is available if more detailed analysis is required.

There is also the possibility that the first instance of a target in the simulation could be at or near the OPLAT. This is not realistic but was difficult to design out of the simulation. As such it is accepted as possible reason for skewed results (the target would reach the OPLAT before it could even be pursued by the UAS). Such instances should not be counted against any UAS system but in this case they may have been.

3. Conclusion

Taking both on station time and efficiency of neutralization into account it seems like a “Rotary Wing” airframe solution is the better option. The TAG M100 is a good example of such a solution; however it is currently under development. It may be too risky to pursue an unproven solution, so the Fire Scout UAS would be an acceptable second choice since it is more proven technology. Either way, multiple rotary wing air vehicles (2 or more) should be procured to maximize on station time and allow at least one vehicle to be on station while the other is refueling or reloading weapons.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. SELECT PREFERRED CONCEPT ALTERNATIVE

The “Rotary Wing” airframe was selected as the preferred concept from the analyses previously discussed in this report. The reasons for this selection include:

- Satisfactorily meets the defined requirements and related MOE’s as indicated by the morphological matrix results.
- Best performance for the dollar as indicated in “bang versus buck” analysis.
- Marginally better risk as determined by the risk analysis.
- Superior operational capabilities as revealed by modeling and simulation.

Specifically, the TAG M100 may be a UAS worth further investigation. At the writing of this report, it is still under development. Another UAS of similar concept is the MQ-8B Fire Scout UAS. The MQ-8B Fire Scout [18] is an unmanned autonomous helicopter developed for use by the United States armed forces to provide reconnaissance, situational awareness, and precision targeting support. Since a “Rotary Wing” airframe would provide the best solution, the data in Table 21 would be excellent source of information to apply cost estimating relationships to further refine life cycle cost estimates for the VULTURE system. Performance levels to assist in developing cost estimating relationships are contained in Table 22.

Table 21: Fire Scout Life Cycle Costs

Cost Type	TY$M
Research, Development, Test & Evaluation (RDT&E)	530.3
Procurement	1,821.5
Military construction	126
Acquisition operating & maintenance	309.3
Operating & support	9,116.6
Total	**11,903.7**

Table 22: Fire Scout Performance Metrics

Performance	Fire Scout 
Length	23.95 ft
Wingspan	-
Height	9.71 ft
Empty weight (lb)	2,073
Maximum Takeoff Gross weight (lb)	3,150
Range (nm)	110
Endurance	8 hours
Service ceiling (ft)	20,000
Maximum Speed	115 knots
Payload Weight	600 lbs
Rotor diameter	27.5 ft

B. CONCLUSIONS

The VULTURE system was de-scoped from the original start of the project so only the surface vessel threat was assessed. Consideration of other types of threats could result in different type of system or systems earning the top performance.

In this research study, the VULTURE system was analyzed strictly as an OCONUS UAS. To operate in CONUS would require various laws and modifications outside the scope of this analysis.

The VULTURE system architecture was developed using the Vitech CORE 6.0 software program. This is an excellent software tool, which was effectively used to identify top-level functions and then decompose them into lower levels.

The morphological matrix process can produce rational results. We were able to base our proposed systems on subjective assignment of values by experienced VULTURE team members and feedback from SMEs.

Most of the analysis in this report focused on a suitable air vehicle type to support the OPLAT defense mission and ideally minimize the manpower footprint. While the

preferred air vehicle is indicated above along with supporting reasons, there are other components that will make up the VULTURE system. Based on research there was some established research space devoted to a sensor sub-system and a command and control sub-system. Recommendations in these areas can be reviewed via the following documentation:

- Sensor: Market Survey for NAVAIR PMA-263 Sea Scout Program [15]
- Command and Control: Proposed Functional Architecture and Associated Benefits Analysis of a Common Ground Control Station for Unmanned Aircraft Systems [16].

The simulation indicates that in order to maximize on station time and mitigate threats to the OPLAT, multiple (2 or more) UAS vehicles should be procured per oil platform being defended.

C. RECOMMENDATIONS

Listed below are the eight recommendations suggested by the VULTURE team. The eight recommendations can be divided into three areas of focus. The first would be current operations of the fleet performing infrastructure protection and UAS utilization. The second area and highest priority would be regarding a programmatic focus on utilizing this report with the updated information developed through an actual program of record. This includes but is not limited to values for the MOEs, a more detailed cost estimate, and further utilization of the functional architecture. The third and final area focuses on the future or long-term goals of implementation of the VULTURE system; these include the possibility of foreign military sales and development of robust rules of engagement.

1) Conduct future research regarding the sensitive nature of infrastructure protection abroad and how it can be improved with the utilization of a UAS.
2) Analyze current UAS operations to ensure that incorporation of the UAS will avoid growth in footprint with respect to logistics or manpower.
3) Develop values for the metrics assigned to the MOEs.

4) Investigate the viability of making a VULTURE system available for foreign military sales.
5) Perform future design efforts that utilize the functional architecture to accomplish the following tasks: (1) Develop a failure modes and effects analysis showing loss of functions; (2) Identify diagnostics requirements to monitor safety critical functions; (3) Determine critical operational issues for evaluation during testing; and (4) Allocate operation of the function to either hardware, software, or human.
6) Investigate specific performance levels and document them using the House of Quality process.
7) Conduct a more detailed cost estimate as the system is developed, and determine cost estimating relationships for various UAS performance levels.
8) Develop rules of engagement using responsible and mature criteria to minimize mistakes in identification and possible engagement of friendly contacts mistakenly targeted as threats.

VII. REFERENCES

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APPENDIX A ACRONYMS

Ao	Operational Availability
AoA	Analysis of Alternatives
APB	Acquisition Program Baseline
C^2	Command & Control
C^3	Command, Control & Communication
C^4I	Command, Control, Communication, Computing & Intelligence
CCJO	Capstone Concept for Joint Operations
COA	Concept of Alternative
CONOPS	Concept of Operations
CONUS	Continental United States
DHS	Department of Homeland Security
DoD	Department of Defense
EFFBD	Enhanced Functional Free Block Diagram
EO/IR	Electro Optical / Infra Red
FND	Focused Noise Device
FW	Fixed Wing
ID	Identification
IDEF	Integration Definition for Function Modeling
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
IPR	Interim Project Review
IPT	Integrated Product Team
ISR	Intelligence, Surveillance, and Reconnaissance
JCA	Joint Capabilities Area
JFC	Joint Functional Concept
JIC	Joint Integrating Concepts
JOC	Joint Operating Concepts
JOpsC-DP	Joint Operations Concept Development Process
KPP	Key Performance Parameter
LTA	Lighter Than Air
MEG-2	Maritime Expeditionary Group 2
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOS	Measure of Suitability
MRL	Manufacturing Readiness Level
MSSE	Master of Science in Systems Engineering
MTBF	Mean Time Between Failure
NAVAIR	Naval Air Systems Command
NAWCAD	Naval Air Warfare Command Aircraft Division
NECC	Naval Expeditionary Combat Command

NPS	Naval Postgraduate School
OCONUS	Outside the Continental United States
OPLAT	Oil Platform
O&S	Operations and Support
P_k	Probability of a Kill
PMA	Program Management Activity
QFD	Quality Function Deployment
RDT&E	Research Development Test & Evaluation
ROE	Rules Of Engagement
RW	Rotary Wing
S&T	Science & Technology
SAR	Synthetic Aperture Radar
SE	Systems Engineering
SME	Subject Matter Expert
STUAS	Small Tactical Unmanned Aerial System
SYSCOM	Systems Command
TEMP	Test and Evaluation Master Plan
TPM	Technical Performance Measure
UAS	Unmanned Aerial System(s)
UCAS-D	Unmanned Combat Air System- Demonstration
UJTL	Universal Joint Task List
UNTL	Universal Naval Task List
US	United States
VULTURE	Variable Mode Unmanned long Range tracking Unit for Reconnaissance & Elimination

APPENDIX B TEAM MEMBERS

Table 23: VULTURE Team Project Members

Name	NAVAIR position	Team Position
Bartolomeo, Peter	4.1.8.2	Risk Assessment and Analysis
McCartney, William	5.1.6.4	Integration and Continuity
Nixon, Rebeca	4.1.1.1	Deputy Project Manager, and Alternatives
Plessinger, Jack	4.1.8	Technical Performance, IMP and IMS
Tebbano, Andrew	5.1.2.4	Project Manager, Modeling and Simulation
Westervelt, Kerry	4.1.1.3	Architecture, Mission Analysis, and Cost
Woodson, Shawn	4.3.2.1	Configuration Management and Control

APPENDIX C MISSION ANALYSIS DEFINITIONS

1. Joint Operations Concepts Definitions

CCJO: Overarching concept that guides the development of future joint force capabilities. It broadly describes how the joint force is expected to operate 8-20 years in the future in all domains across the range of military operations within a multilateral environment and in collaboration with interagency and multilateral partners.

JOCs: Applies the CCJO solution in greater detail to a specified mission area, and describes how a joint force commander, 8-20 years in the future, is expected to conduct operations within a military campaign.

JFCs: Applies elements of the capstone concept for joint operations solution to describe how the joint force, 8-20 years in the future, will perform an enduring military function across the full range of military operations, and identifies the operational-level capabilities required to support the full range of military operations. Also determines any additional military capabilities required to create the effects identified in JOCs.

JICs: Operational-level description of how a joint force commander, 8-20 years in the future, will perform a specific operation or function derived from a joint operating concept and/or a joint functional concept. They are narrowly scoped to identify, describe, and apply specific military capabilities, decomposing them into fundamental tasks, conditions, and standards.

Based upon this concept, the VULTURE team intends to define the mission supporting the objective of developing an affordable technology based solution to protect and defend sea based OPLATs from terrorist attack.

2. Joint Capabilities Areas

DoD has adopted JCAs as its capability management language and framework as explained in the Chairman of the Joint Chiefs of Staff Instruction 3170.01G [19]. JCAs are collections of DoD capabilities functionally grouped to support capability analysis, strategy development, investment decision making, and capabilities-based force development and operational planning. A list of all JCAs can be found at

http://www.dtic.mil/futurejointwarfare/. The JCA associated with meeting the objectives of the VULTURE system is “Protection”. Protection is defined as the ability to prevent/mitigate adverse effects of attacks on personnel (combatant/non-combatant) and physical assets of the United States, and allies. The definition for each element is provided in paragraph 3, and they were obtained from the J7 Joint Force Development and Integration Division website [20]. Of the JCAs in Figure 31, only item “7.1 Prevent” and its sub-elements apply to the VULTURE system.

7. <u>Protection</u>

7.1 Prevent
7.1.1 Prevent Kinetic Attack
7.1.1.1 Above (PK)
7.1.1.1.1 Maneuvering (PKA)
7.1.1.1.2 Non-Maneuvering (PKA)
7.1.1.2 Surface (PK)
7.1.1.2.1 Maneuvering (PKS)
7.1.1.2.2 Non-Maneuvering (PKS)
7.1.1.3 Sub-surface Kinetic (PK)
7.1.1.3.1 Maneuvering (PKSS)
7.1.1.3.2 Non-Maneuvering (PKSS)
7.1.2 Prevent Non-kinetic Attack
7.1.2.1 Above Surface (PN)
7.1.2.2 Surface (PN)
7.1.2.3 Sub-Surface (PN)
7.2 Mitigate
7.2.1 Mitigate Lethal Effects
7.2.1.1 Chemical (ML)
7.2.1.2 Biological (ML)
7.2.1.2.1 Contagious (MLB)
7.2.1.2.2 Non-contagious (MLB)
7.2.1.3 Radiological (ML)
7.2.1.4 Nuclear (ML)
7.2.1.5 Electro Magnetic Pulse (ML)
7.2.1.6 Explosives (ML)
7.2.1.7 Projectiles (ML)
7.2.1.8 Directed Energy (ML)
7.2.1.9 Natural Hazards (ML)
7.2.2 Mitigate Non-lethal Effects
7.2.2.1 Chemical (MN)
7.2.2.2 Biological (MN)
7.2.2.2.1 Contagious (MNB)
7.2.2.2.2 Non-contagious (MNB)
7.2.2.3 Electro Magnetic Pulse (MN)
7.2.2.4 Explosives (MN)
7.2.2.5 Projectiles (MN)
7.2.2.6 Directed Energy (MN)
7.2.2.7 Electro-Magnetic Spectrum (MN)
7.2.2.8 Natural Hazards (MN)
7.3 **Research and Development**
7.3.1 Basic Research
7.3.2 Applied Research
7.3.3 Advanced Technology Development

Figure 31: Protection JCA Elements

3. Protection JCA Definitions

1 Protection – The ability to prevent/mitigate adverse effects of attacks on personnel (combatant/non-combatant) and physical assets of the United States, allies and friends.

1.1 Prevent – The ability to neutralize an imminent attack or defeat attacks on personnel (combatant/non-combatant) and physical assets.

1.1.1 Prevent Kinetic Attack – The ability to defeat attacks being delivered by systems which rely upon physical momentum.

1.1.1.1 Above Surface (PK) – The ability to defeat kinetically delivered attacks in air and space.

1.1.1.1.1 Maneuvering (PKA) – The ability to defeat kinetically delivered attacks that can change speed, direction or altitude based on internal or external guidance.

1.1.1.1.2 Non-Maneuvering (PKA) – The ability to defeat kinetically delivered attacks that cannot change speed, direction or altitude based on internal or external guidance.

1.1.1.2 Surface (PK) – The ability to defeat kinetically delivered attacks on the exterior or upper boundary of the land or water.

1.1.1.2.1 Maneuvering (PKS) – The ability to defeat kinetically delivered attacks that can change speed or direction based on internal or external guidance.

1.1.1.2.2 Non-Maneuvering (PKS) – The ability to defeat kinetically delivered attacks that cannot change speed or direction based on internal or external guidance.

1.1.1.3 Sub-Surface Kinetic (PK) – The ability to defeat kinetically delivered attacks beneath the surface of the earth (bunkers, basements, tunnels, caves, etc.) or beneath the surface of a body of water.

1.1.1.3.1 Maneuvering (PKSS) – The ability to defeat kinetically delivered attacks that can change speed, direction or depth based on internal or external guidance.

1.1.1.3.2 Non-Maneuvering (PKSS) – The ability to defeat kinetically delivered attacks that cannot change speed, direction or depth based on internal or external guidance.

1.1.2 Prevent Non-kinetic Attack – The ability to defeat attacks being delivered by systems which do not rely upon physical momentum.

1.1.2.1 Above Surface (PN) – The ability to defeat non-kinetically delivered attacks in air and space.

1.1.2.2 Surface (PN) – The ability to defeat non-kinetically delivered attacks on the exterior or upper boundary of the land or water.

1.1.2.3 Sub-Surface (PN) – The ability to defeat non-kinetically delivered attacks beneath the surface of the earth (bunkers, basements, tunnels, caves, etc.) or beneath the surface of a body of water.

1.2 Mitigate – The ability to minimize the effects and manage the consequence of attacks (and designated emergencies on personnel and physical assets.

1.2.1 Mitigate Lethal Effects – The ability to minimize the effects of attacks or designated emergencies which have the potential to kill personnel and destroy physical assets.

1.2.1.1 Chemical (ML) – The ability to minimize the effects of chemical attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.2 Biological (ML) – The ability to minimize the effects of biological attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.2.1 Contagious (MLB) – The ability to minimize the effects of contagious biological attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.2.2 Non-Contagious (MLB) – The ability to minimize the effects of non-contagious biological attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.3 Radiological (ML) – The ability to minimize the effects of radiological attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.4 Nuclear (ML) – The ability to minimize the effects of nuclear attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.5 Electromagnetic Pulse (ML) – The ability to minimize the effects of electromagnetic pulse attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.6 Explosives (ML) – The ability to minimize the effects of explosive attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.7 Projectiles (ML) – The ability to minimize the effects of projectile attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.8 Directed Energy (ML) – The ability to minimize the effects of directed energy attacks which have the potential to kill personnel and destroy physical assets.

1.2.1.9 Natural Hazards (ML) – The ability to minimize the effects of natural hazards which have the potential to kill personnel and destroy physical assets.

1.2.2 Mitigate Non-Lethal Effects – The ability to minimize the effects of attacks or designated emergencies which do not have the potential to kill personnel and destroy physical assets.

1.2.2.1 Chemical (MN) – The ability to minimize the effects of chemical attacks which do not have the potential to kill personnel and destroy physical assets.

1.2.2.2 Biological (MN) – The ability to minimize the effects of biological attacks which do not have the potential to kill personnel and destroy physical assets.

1.2.2.2.1 Contagious (MNB) – The ability to minimize the effects of contagious biological attacks which do not have the potential to kill personnel and destroy physical assets.

1.2.2.2.2 Non-Contagious (MNB) – The ability to minimize the effects of non-contagious biological attacks which do not have the potential to kill personnel and destroy physical assets.

1.2.2.3 Electromagnetic Pulse (MN) – The ability to minimize the effects of electromagnetic pulse attacks which do not have the potential to kill personnel and destroy physical assets.

1.2.2.4 Explosives (MN) – The ability to minimize the effects of explosive attacks which do not have the potential to kill personnel and destroy physical assets.

1.2.2.5 Projectiles (MN) – The ability to minimize the effects of projectile attacks which do not have the potential to kill personnel and destroy physical assets.

1.2.2.6 Directed Energy (MN) – The ability to minimize the effects of directed energy attacks which do not have the potential to kill personnel and destroy physical assets.

1.2.2.7 Electromagnetic Spectrum (MN) – The ability to minimize the effects of electromagnetic spectrum attacks which do not have the potential to kill personnel and destroy physical assets.

1.2.2.8 Natural Hazards (MN) – The ability to minimize the effects of natural hazards which do not have the potential to kill personnel and destroy physical assets.

1.3 Research and Development – The ability to conduct fundamental research, science, technology, development and experimentation important to all Departmental capabilities and operations

1.3.1 Basic Research – The ability to conduct a systematic study directed toward the discovery of knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications.

1.3.2 Applied Research – The ability to conduct a systematic study to understand the means to meet a recognized and specific need.

1.3.3 Advanced Technology Development – The ability to produce innovative and unique components and prototypes that can be integrated into defense systems for field experiments and/or tests in a simulated "or operational" environment "to assess military utility" prior to full development.

APPENDIX D VULTURE ARCHITECTURE DETAILS

The further decomposition of the VULTURE IDEF 0 diagram (shown in Figure 21) is detailed in an IDEF level 1 diagram shown in Figure 32, Figure 33, Figure 34, Figure 35 and Figure 36. It shows the tier 2 level functions and their interrelationships. Inputs and outputs from the system are identified along with the signals passed between the various functions. It is very similar to the N^2 diagram except the inputs and outputs are better illustrated along with the interconnecting lines. Furthermore, the physical components are shown at the bottom of each tier 2 function that it supports.

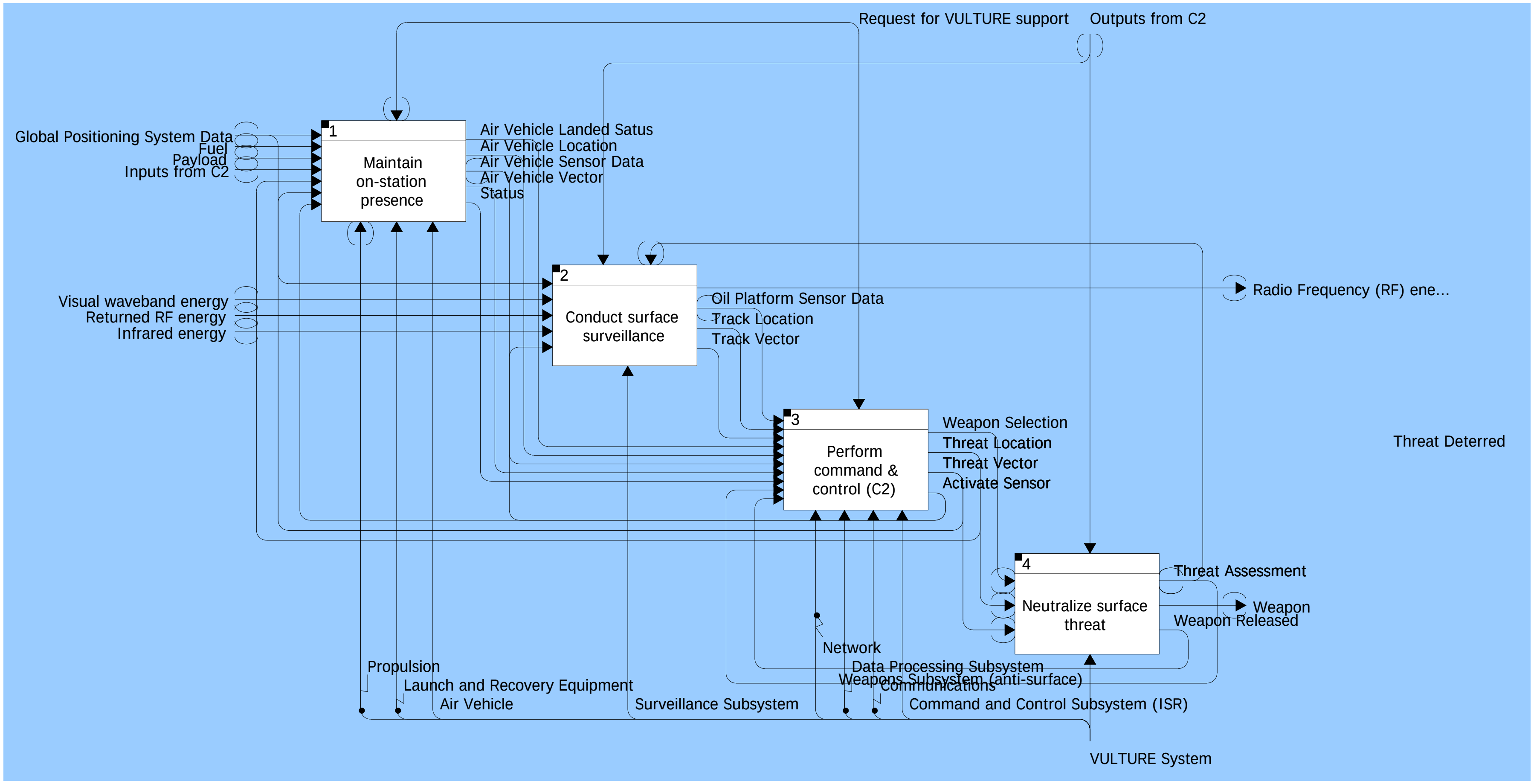


Figure 32: VULTURE Functional IDEF1 Diagram

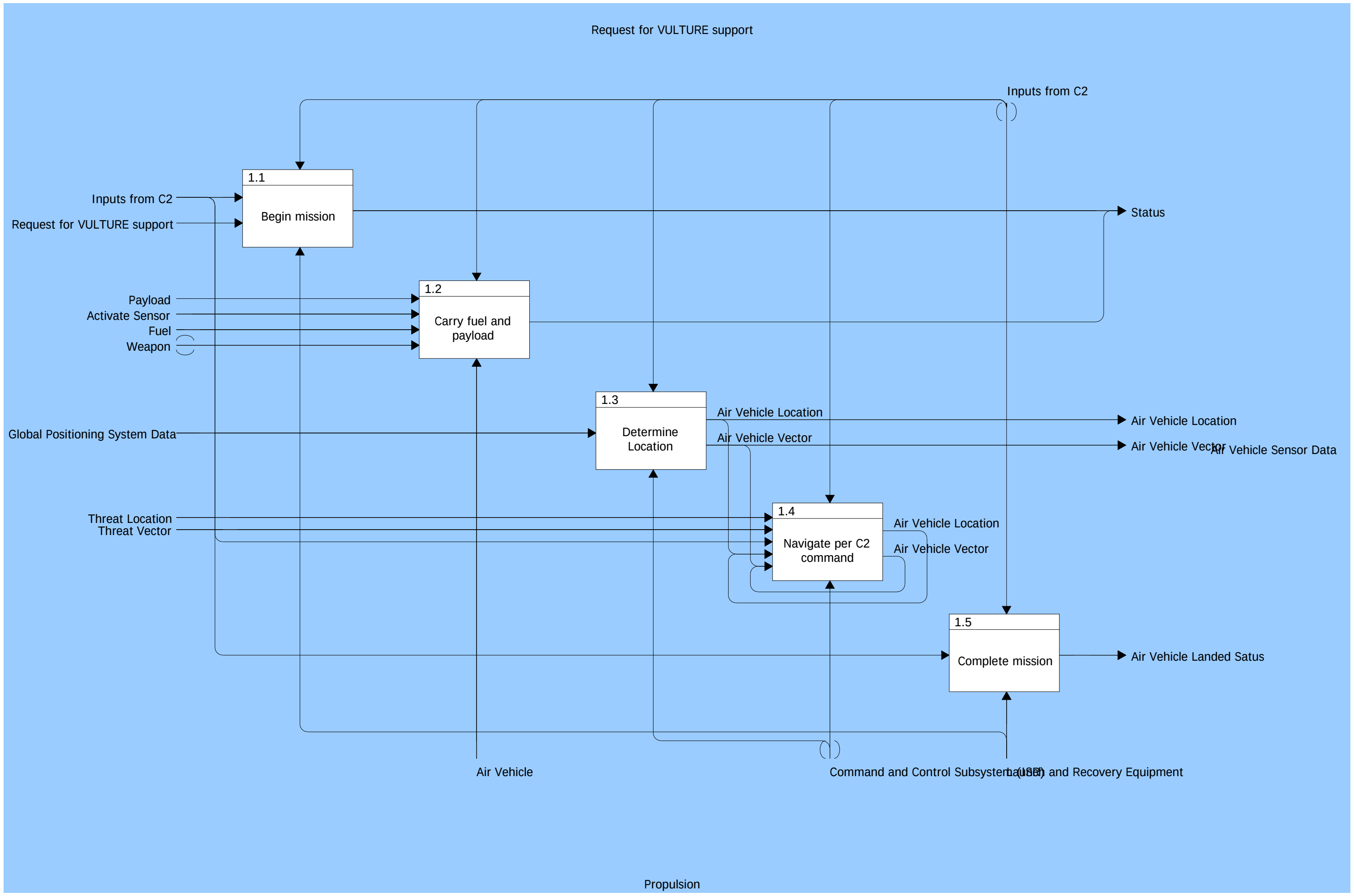


Figure 33: Maintain On-Station Presence IDEF1 Diagram

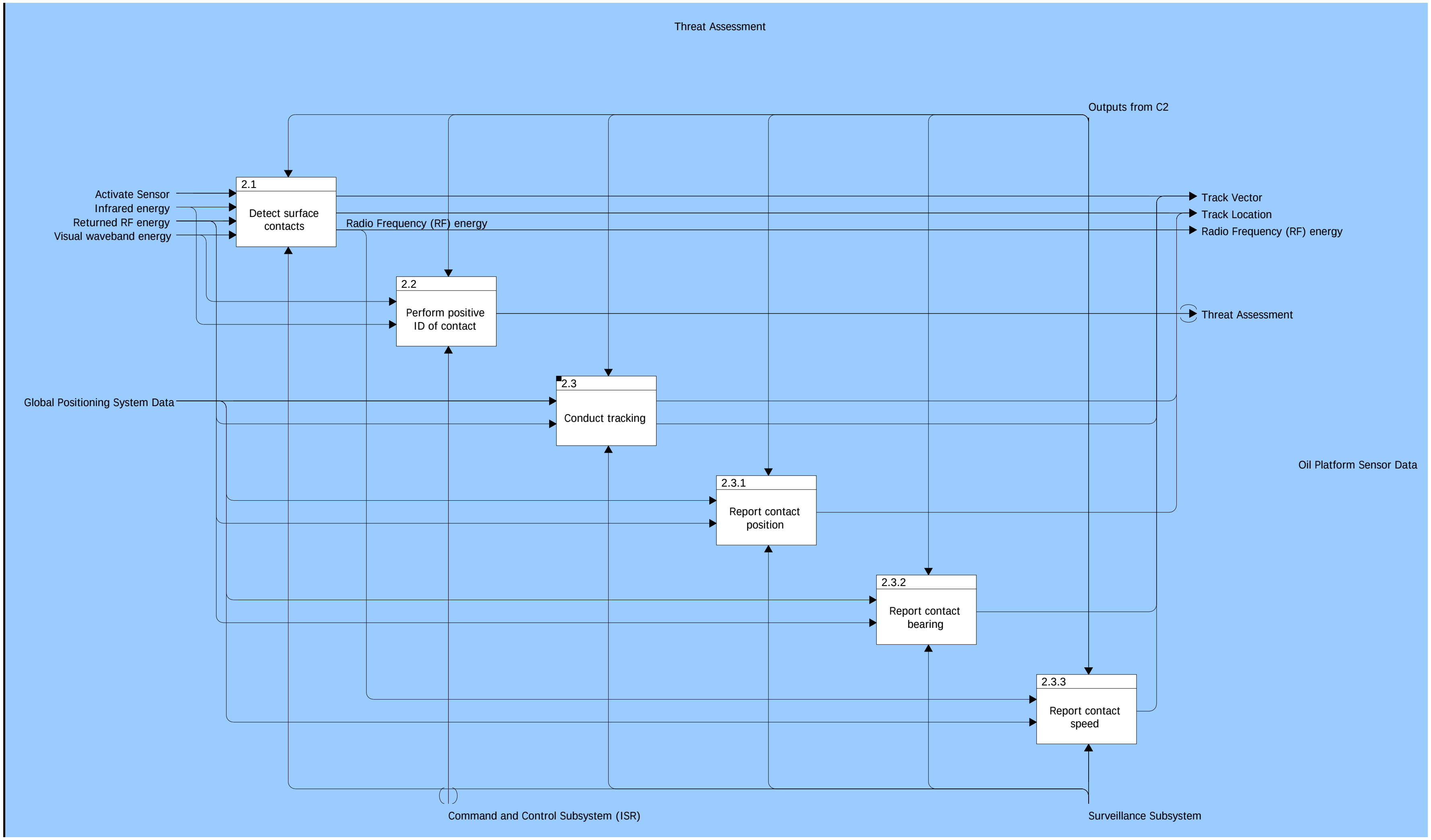


Figure 34: Conduct Surface Surveillance IDEF1 Diagram

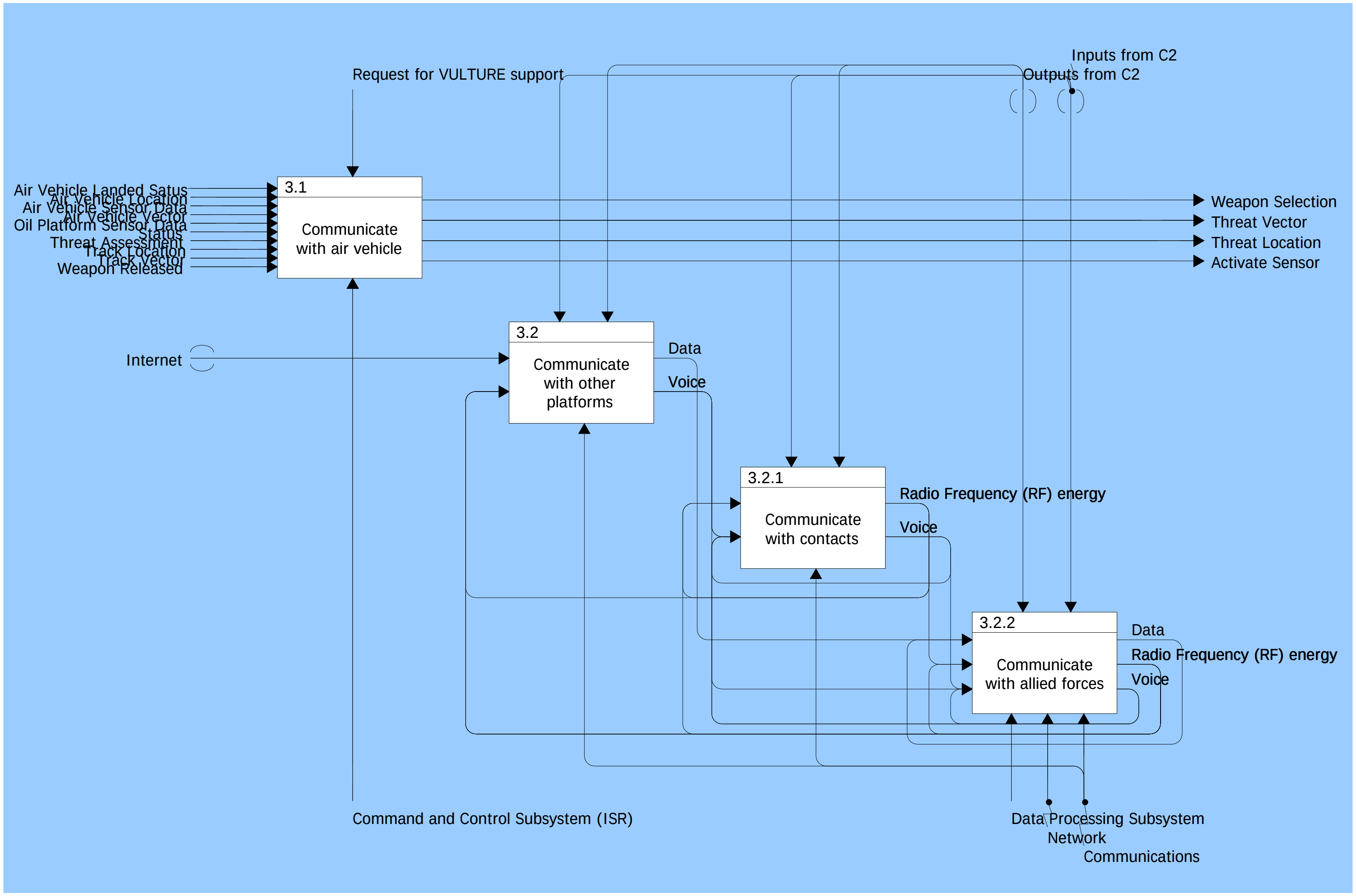


Figure 35: Perform Command and Control IDEF1 Diagram

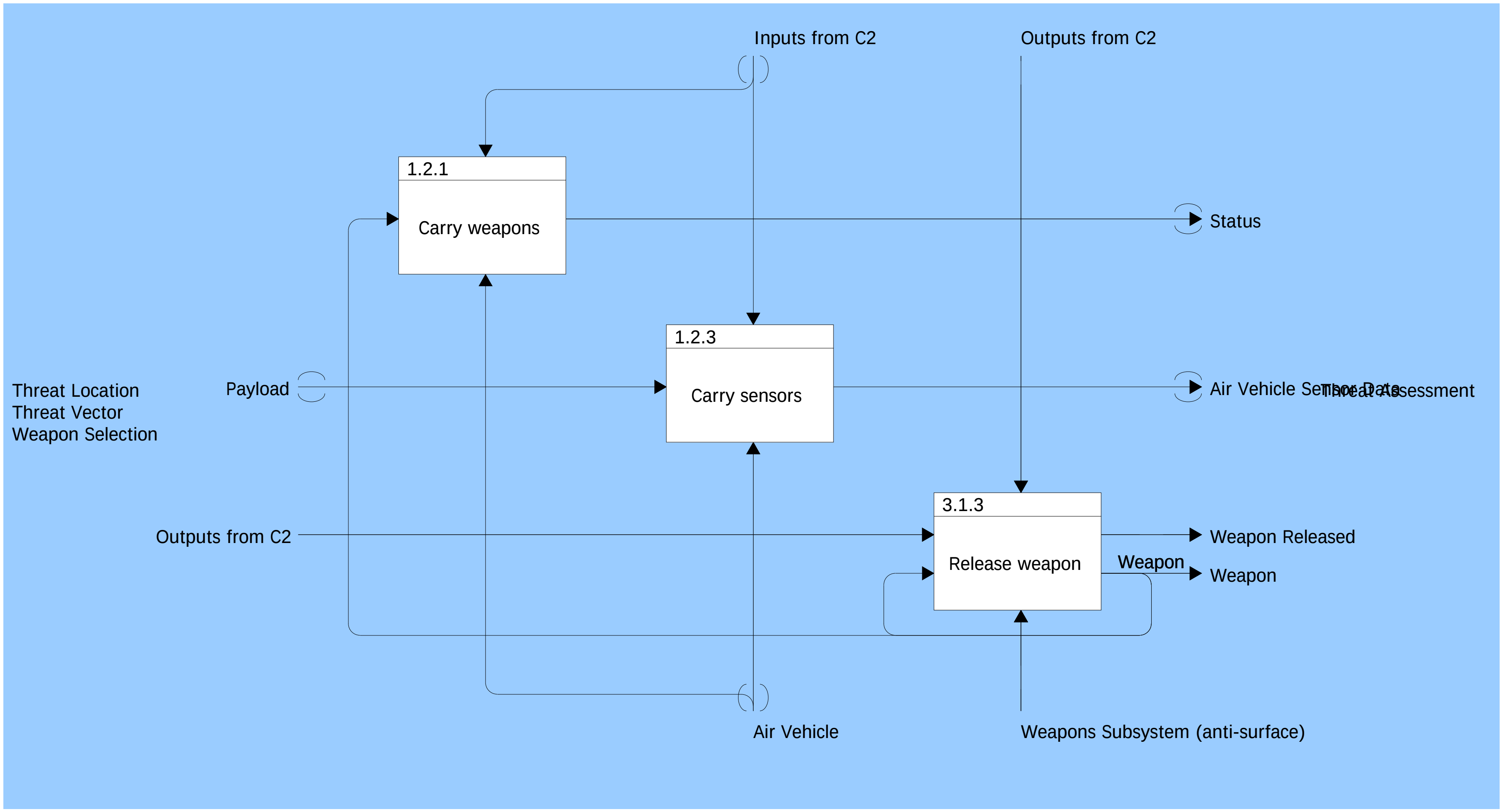


Figure 36: Neutralize Surface Threat IDEF1 Diagram

APPENDIX E MORPHOLOGICAL MATRIX SAMPLE

The morphological matrix is too large a file to include in its entirety. To avoid inundating the reader to a 39,366 row matrix excel sheet (493 page pdf) the following three pages are included to give a taste of the permutations that took place.

	Weapons		Surveillance		Propulsion		Launch/Recovery Equipment		Air Vehicle	
Configuration Number	Non-Lethal	Lethal	Active	Passive	Power Plant	Fuel	Launch	Recovery	Airframe	Navigation/Guidance
1	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Ship	Rotary Wing	INS
2	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Ship	Rotary Wing	GPS
3	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Ship	Rotary Wing	EGI
4	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Ship	Fixed Wing	INS
5	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Ship	Fixed Wing	GPS
6	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Ship	Fixed Wing	EGI
7	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Ship	Lighter than Air	INS
8	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Ship	Lighter than Air	GPS
9	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Ship	Lighter than Air	EGI
10	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Land	Rotary Wing	INS
11	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Land	Rotary Wing	GPS
12	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Land	Rotary Wing	EGI
13	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Land	Fixed Wing	INS
14	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Land	Fixed Wing	GPS
15	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Land	Fixed Wing	EGI
16	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Land	Lighter than Air	INS
17	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Land	Lighter than Air	GPS
18	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Land	Lighter than Air	EGI
19	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Oil Platform	Rotary Wing	INS
20	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Oil Platform	Rotary Wing	GPS
21	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Oil Platform	Rotary Wing	EGI
22	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Oil Platform	Fixed Wing	INS
23	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Oil Platform	Fixed Wing	GPS
24	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Oil Platform	Fixed Wing	EGI
25	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Oil Platform	Lighter than Air	INS
26	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Oil Platform	Lighter than Air	GPS
27	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Ship	Oil Platform	Lighter than Air	EGI
28	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Ship	Rotary Wing	INS
29	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Ship	Rotary Wing	GPS
30	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Ship	Rotary Wing	EGI
31	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Ship	Fixed Wing	INS
32	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Ship	Fixed Wing	GPS
33	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Ship	Fixed Wing	EGI
34	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Ship	Lighter than Air	INS
35	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Ship	Lighter than Air	GPS
36	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Ship	Lighter than Air	EGI
37	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Land	Rotary Wing	INS
38	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Land	Rotary Wing	GPS
39	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Land	Rotary Wing	EGI
40	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Land	Fixed Wing	INS
41	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Land	Fixed Wing	GPS
42	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Land	Fixed Wing	EGI
43	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Land	Lighter than Air	INS
44	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Land	Lighter than Air	GPS
45	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Land	Lighter than Air	EGI
46	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Oil Platform	Rotary Wing	INS
47	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Oil Platform	Rotary Wing	GPS
48	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Oil Platform	Rotary Wing	EGI
49	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Oil Platform	Fixed Wing	INS
50	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Oil Platform	Fixed Wing	GPS
51	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Oil Platform	Fixed Wing	EGI
52	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Oil Platform	Lighter than Air	INS
53	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Oil Platform	Lighter than Air	GPS
54	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Land	Oil Platform	Lighter than Air	EGI
55	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Ship	Rotary Wing	INS
56	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Ship	Rotary Wing	GPS
57	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Ship	Rotary Wing	EGI
58	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Ship	Fixed Wing	INS
59	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Ship	Fixed Wing	GPS
60	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Ship	Fixed Wing	EGI
61	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Ship	Lighter than Air	INS
62	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Ship	Lighter than Air	GPS
63	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Ship	Lighter than Air	EGI
64	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Land	Rotary Wing	INS
65	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Land	Rotary Wing	GPS
66	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Land	Rotary Wing	EGI
67	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Land	Fixed Wing	INS
68	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Land	Fixed Wing	GPS
69	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Land	Fixed Wing	EGI
70	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Land	Lighter than Air	INS
71	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Land	Lighter than Air	GPS
72	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Land	Lighter than Air	EGI
73	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Oil Platform	Rotary Wing	INS
74	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Oil Platform	Rotary Wing	GPS
75	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Oil Platform	Rotary Wing	EGI
76	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Oil Platform	Fixed Wing	INS
77	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Oil Platform	Fixed Wing	GPS
78	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
79	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Oil Platform	Lighter than Air	INS
80	Visual	Rockets	RADAR	EO/IR	Jet	JP-5	Oil Platform	Oil Platform	Lighter than Air	GPS

Figure 37: Image capture of a portion of the Morphological Matrix

	Weapons		Surveillance		Propulsion		Launch/Recovery Equipment		Air Vehicle	
Configuration Number	Non-Lethal	Lethal	Active	Passive	Power Plant	Fuel	Launch	Recovery	Airframe	Navigation/Guidance
9041	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Land	Oil Platform	Fixed Wing	GPS
9042	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Land	Oil Platform	Fixed Wing	EGI
9043	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Land	Oil Platform	Lighter than Air	INS
9044	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Land	Oil Platform	Lighter than Air	GPS
9045	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Land	Oil Platform	Lighter than Air	EGI
9046	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Ship	Rotary Wing	INS
9047	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Ship	Rotary Wing	GPS
9048	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Ship	Rotary Wing	EGI
9049	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Ship	Fixed Wing	INS
9050	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Ship	Fixed Wing	GPS
9051	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Ship	Fixed Wing	EGI
9052	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Ship	Lighter than Air	INS
9053	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Ship	Lighter than Air	GPS
9054	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Ship	Lighter than Air	EGI
9055	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Land	Rotary Wing	INS
9056	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Land	Rotary Wing	GPS
9057	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Land	Rotary Wing	EGI
9058	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Land	Fixed Wing	INS
9059	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Land	Fixed Wing	GPS
9060	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Land	Fixed Wing	EGI
9061	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Land	Lighter than Air	INS
9062	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Land	Lighter than Air	GPS
9063	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Land	Lighter than Air	EGI
9064	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Oil Platform	Rotary Wing	INS
9065	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Oil Platform	Rotary Wing	GPS
9066	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Oil Platform	Rotary Wing	EGI
9067	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Oil Platform	Fixed Wing	INS
9068	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Oil Platform	Fixed Wing	GPS
9069	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
9070	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Oil Platform	Lighter than Air	INS
9071	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Oil Platform	Lighter than Air	GPS
9072	Visual	Missiles	RADAR	EO/IR	Propeller	JP-5	Oil Platform	Oil Platform	Lighter than Air	EGI
9073	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Ship	Rotary Wing	INS
9074	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Ship	Rotary Wing	GPS
9075	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Ship	Rotary Wing	EGI
9076	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Ship	Fixed Wing	INS
9077	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Ship	Fixed Wing	GPS
9078	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Ship	Fixed Wing	EGI
9079	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Ship	Lighter than Air	INS
9080	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Ship	Lighter than Air	GPS
9081	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Ship	Lighter than Air	EGI
9082	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Land	Rotary Wing	INS
9083	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Land	Rotary Wing	GPS
9084	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Land	Rotary Wing	EGI
9085	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Land	Fixed Wing	INS
9086	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Land	Fixed Wing	GPS
9087	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Land	Fixed Wing	EGI
9088	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Land	Lighter than Air	INS
9089	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Land	Lighter than Air	GPS
9090	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Land	Lighter than Air	EGI
9091	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Oil Platform	Rotary Wing	INS
9092	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Oil Platform	Rotary Wing	GPS
9093	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Oil Platform	Rotary Wing	EGI
9094	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Oil Platform	Fixed Wing	INS
9095	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Oil Platform	Fixed Wing	GPS
9096	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Oil Platform	Fixed Wing	EGI
9097	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Oil Platform	Lighter than Air	INS
9098	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Oil Platform	Lighter than Air	GPS
9099	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Ship	Oil Platform	Lighter than Air	EGI
9100	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Ship	Rotary Wing	INS
9101	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Ship	Rotary Wing	GPS
9102	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Ship	Rotary Wing	EGI
9103	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Ship	Fixed Wing	INS
9104	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Ship	Fixed Wing	GPS
9105	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Ship	Fixed Wing	EGI
9106	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Ship	Lighter than Air	INS
9107	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Ship	Lighter than Air	GPS
9108	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Ship	Lighter than Air	EGI
9109	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Land	Rotary Wing	INS
9110	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Land	Rotary Wing	GPS
9111	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Land	Rotary Wing	EGI
9112	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Land	Fixed Wing	INS
9113	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Land	Fixed Wing	GPS
9114	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Land	Fixed Wing	EGI
9115	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Land	Lighter than Air	INS
9116	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Land	Lighter than Air	GPS
9117	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Land	Lighter than Air	EGI
9118	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Oil Platform	Rotary Wing	INS
9119	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Oil Platform	Rotary Wing	GPS
9120	Visual	Missiles	RADAR	EO/IR	Propeller	Battery	Land	Oil Platform	Rotary Wing	EGI

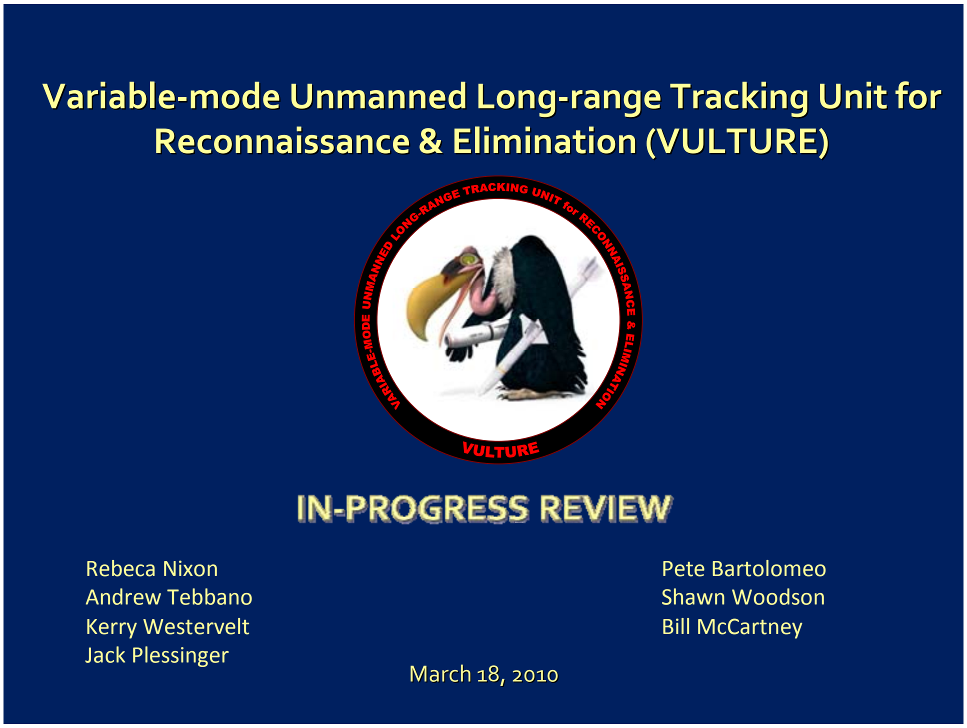
Figure 38: Image Capture of a portion of the Morphological Matrix cont.

	Weapons		Surveillance		Propulsion		Launch/Recovery Equipment		Air Vehicle	
Configuration Number	Non-Lethal	Lethal	Active	Passive	Power Plant	Fuel	Launch	Recovery	Airframe	Navigation/Guidance
39201	Electromagneti	Missiles	SONAR	ESM	Air	JP-5	Oil Platform	Oil Platform	Fixed Wing	EGI
39202	Electromagneti	Missiles	SONAR	ESM	Air	JP-5	Oil Platform	Oil Platform	Lighter than Air	INS
39203	Electromagneti	Missiles	SONAR	ESM	Air	JP-5	Oil Platform	Oil Platform	Lighter than Air	GPS
39204	Electromagneti	Missiles	SONAR	ESM	Air	JP-5	Oil Platform	Oil Platform	Lighter than Air	EGI
39205	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Ship	Rotary Wing	INS
39206	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Ship	Rotary Wing	GPS
39207	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Ship	Rotary Wing	EGI
39208	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Ship	Fixed Wing	INS
39209	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Ship	Fixed Wing	GPS
39210	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Ship	Fixed Wing	EGI
39211	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Ship	Lighter than Air	INS
39212	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Ship	Lighter than Air	GPS
39213	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Ship	Lighter than Air	EGI
39214	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Land	Rotary Wing	INS
39215	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Land	Rotary Wing	GPS
39216	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Land	Rotary Wing	EGI
39217	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Land	Fixed Wing	INS
39218	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Land	Fixed Wing	GPS
39219	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Land	Fixed Wing	EGI
39220	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Land	Lighter than Air	INS
39221	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Land	Lighter than Air	GPS
39222	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Land	Lighter than Air	EGI
39223	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Oil Platform	Rotary Wing	INS
39224	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Oil Platform	Rotary Wing	GPS
39225	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Oil Platform	Rotary Wing	EGI
39226	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Oil Platform	Fixed Wing	INS
39227	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Oil Platform	Fixed Wing	GPS
39228	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Oil Platform	Fixed Wing	EGI
39229	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Oil Platform	Lighter than Air	INS
39230	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Oil Platform	Lighter than Air	GPS
39231	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Ship	Oil Platform	Lighter than Air	EGI
39232	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Ship	Rotary Wing	INS
39233	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Ship	Rotary Wing	GPS
39234	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Ship	Rotary Wing	EGI
39235	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Ship	Fixed Wing	INS
39236	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Ship	Fixed Wing	GPS
39237	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Ship	Fixed Wing	EGI
39238	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Ship	Lighter than Air	INS
39239	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Ship	Lighter than Air	GPS
39240	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Ship	Lighter than Air	EGI
39241	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Land	Rotary Wing	INS
39242	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Land	Rotary Wing	GPS
39243	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Land	Rotary Wing	EGI
39244	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Land	Fixed Wing	INS
39245	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Land	Fixed Wing	GPS
39246	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Land	Fixed Wing	EGI
39247	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Land	Lighter than Air	INS
39248	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Land	Lighter than Air	GPS
39249	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Land	Lighter than Air	EGI
39250	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Oil Platform	Rotary Wing	INS
39251	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Oil Platform	Rotary Wing	GPS
39252	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Oil Platform	Rotary Wing	EGI
39253	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Oil Platform	Fixed Wing	INS
39254	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Oil Platform	Fixed Wing	GPS
39255	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Oil Platform	Fixed Wing	EGI
39256	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Oil Platform	Lighter than Air	INS
39257	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Oil Platform	Lighter than Air	GPS
39258	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Land	Oil Platform	Lighter than Air	EGI
39259	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Ship	Rotary Wing	INS
39260	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Ship	Rotary Wing	GPS
39261	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Ship	Rotary Wing	EGI
39262	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Ship	Fixed Wing	INS
39263	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Ship	Fixed Wing	GPS
39264	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Ship	Fixed Wing	EGI
39265	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Ship	Lighter than Air	INS
39266	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Ship	Lighter than Air	GPS
39267	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Ship	Lighter than Air	EGI
39268	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Land	Rotary Wing	INS
39269	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Land	Rotary Wing	GPS
39270	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Land	Rotary Wing	EGI
39271	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Land	Fixed Wing	INS
39272	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Land	Fixed Wing	GPS
39273	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Land	Fixed Wing	EGI
39274	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Land	Lighter than Air	INS
39275	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Land	Lighter than Air	GPS
39276	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Land	Lighter than Air	EGI
39277	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Oil Platform	Rotary Wing	INS
39278	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Oil Platform	Rotary Wing	GPS
39279	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Oil Platform	Rotary Wing	EGI
39280	Electromagneti	Missiles	SONAR	ESM	Air	Battery	Oil Platform	Oil Platform	Fixed Wing	INS

Figure 39: Image Capture of a portion of the Morphological Matrix cont.

APPENDIX F IPR 1 SLIDES

IPR #1



Agenda

- Goals for Today
- Project Focus
- Background
- Scope
- Stakeholders
- Needs Analysis
  - Missions
  - CONOPS
  - Scenarios
- Project Plan
- What's Next
- Questions & Feedback
- References

Goals for Today

- Overview of Project Plan and Scope
- Accomplishments to date
- Ongoing analysis
- What's Next
- Feedback

Project Focus

- Due to global terrorist threats targeted at oil production and distribution facilities a DoD need was identified for the capability to provide continuous, all-weather, autonomous protection of domestic and foreign oil platforms.
- Damage or hindrance of the energy infrastructure would severely impact both the US and Global economies, and have dire environmental consequences to the regional locations.

Project Focus

- Due to global terrorist threats targeted at oil production and distribution facilities a DoD need was identified for the capability to provide continuous, all-weather, autonomous protection of domestic and foreign oil platforms.
- Damage or hindrance of the energy infrastructure would severely impact both the US and Global economies, and have dire environmental consequences to the regional locations.

Scope of Project




- Requirements Analysis & Generation
  - Protect and Defend sea-based oil platforms
  - World-wide operational capability
  - Defend U.S. and allied assets
  - Initial Operating Capability (IOC) in 2016
- Research & Analysis
  - Analyze all aspect s of potential solutions
    - Sensor packages
    - Level of autonomy
    - Land, sea or air based; or a combination
    - Weapons load-out & Countermeasures
    - Loitering capability
    - Technology Readiness Levels (TRL)
    - Doctrine, Organization, Training, Materiel, Leadership, Personnel and Facilities (DOTMLPF)


Stakeholders in Successful OPLAT Defense

- *Global – Broad Implications*
  - Oil Industry – Security of Personnel and Commerce
  - Global Economy
  - Host Nations
- *Economic – Monetary Implications*
  - Oil Markets (both global and local)
  - Specific Oil companies
- *Organizational – Build and Implement*
  - U.S. Military (NAVY/MARINES)
    - Acquisition Community
    - Operational Community
      - Combatant Commanders
  - Homeland Security Agencies (COAST GUARD)
  - Intelligence Community
- *Industry*
  - Prime/Sub-Contractors
  - Design
  - Manufacturing
- *Political*
  - Politicians, Service/Appointed Secretaries
  - American Citizens – Security/Mission Accomplishment
- *Individual*
  - Tanker Crews
  - Oil terminal Workers
  - Consumers
  - *UV Operators*
- *Environmental*
  - Waterway Environments
  - Environmentalist Groups

Primary Stakeholders

- Navy Expeditionary Combat Command (NECC)
  - CDR Gary Lauck, N9 (S&T) COMNECC
  - Charlie Sullivan, Maritime Expeditionary Group 2 (MEG-2)
  - CDR John Anderson, N3 (Man, Train, & Equip)
  - http://www.necc.navy.mil/
- Email/Phone call exchanges to date. Working on developing these relationships

Needs Analysis

- **Capability Need Statement**
  - **The VULTURE concept is expected to meet the need to provide real time situational awareness for the purpose of persistent and effective defense of Oil Platforms against conventional and/or unconventional threats.**
- **Key Requirements and Capabilities**
  - **The system must be an affordable solution**
  - **Persistent Intelligence, Surveillance, and Reconnaissance (ISR)**
  - **Capability to engage and destroy threats**
  - **Sustainment strategy that is both affordable and feasible for operations surrounding a remote oil platform.**

Needs Analysis

Capability Need

Stakeholder/SME interviews, Research (NAVSEA Crane Study)

Concept of Operations

(threat profiles, environmental requirements, system constraints, and support infrastructure)

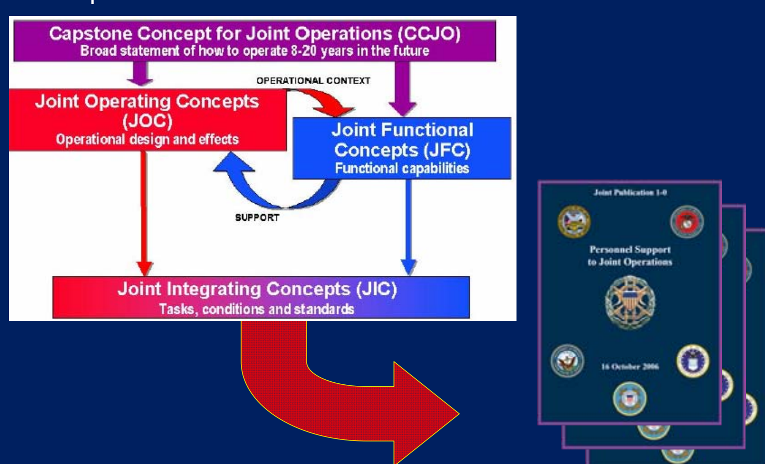
Operational Scenarios

Modeling, Stakeholder/SME interviews, Requirements Generation Tools (pairwise comparisons, QFD)

Functional and Non-functional requirements

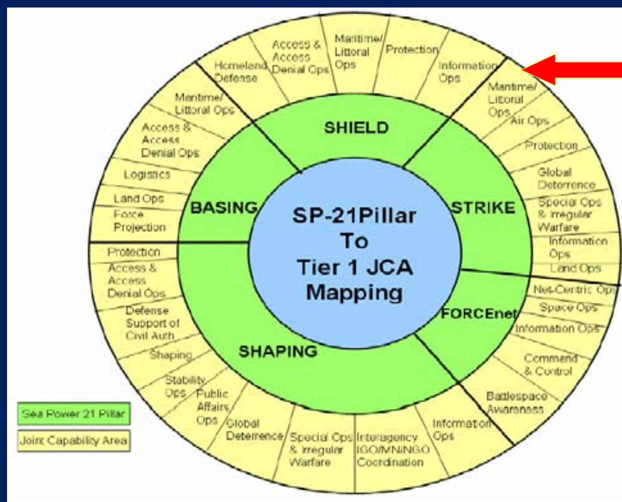
Missions

- Mission analysis performed per Joint Operations Concepts Development Process



Missions Cont'd

- Sea Power 21 Pillar mapped to Tier 1 Joint Capabilities Areas



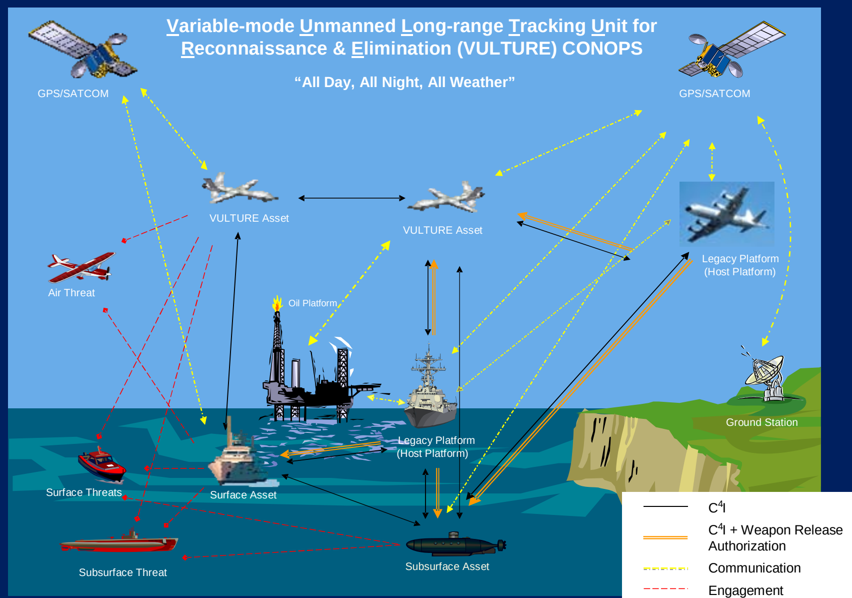
7. **Protection**

7.1 **Prevent**
7.1.1 Prevent Kinetic Attack
7.1.1.1 Above (PK)
7.1.1.1.1 Maneuvering (PKA)
7.1.1.1.2 Non-Maneuvering (PKA)
7.1.1.2 Surface (PK)
7.1.1.2.1 Maneuvering (PKS)
7.1.1.2.2 Non-Maneuvering (PKS)
7.1.1.3 Sub-surface Kinetic (PK)
7.1.1.3.1 Maneuvering (PKSS)
7.1.1.3.2 Non-Maneuvering (PKSS)
7.1.2 Prevent Non-kinetic Attack
7.1.2.1 Above Surface (PN)
7.1.2.2 Surface (PN)
7.1.2.3 Sub-Surface (PN)
7.2 **Mitigate**
7.2.1 Mitigate Lethal Effects
7.2.1.1 Chemical (ML)
7.2.1.2 Biological (ML)
7.2.1.2.1 Contagious (MLB)
7.2.1.2.2 Non-contagious (MLB)
7.2.1.3 Radiological (ML)
7.2.1.4 Nuclear (ML)
7.2.1.5 Electro Magnetic Pulse (ML)
7.2.1.6 Explosives (ML)
7.2.1.7 Projectiles (ML)
7.2.1.8 Directed Energy (ML)
7.2.1.9 Natural Hazards (ML)
7.2.2 Mitigate Non-lethal Effects
7.2.2.1 Chemical (MN)
7.2.2.2 Biological (MN)
7.2.2.2.1 Contagious (MNB)
7.2.2.2.2 Non-contagious (MNB)
7.2.2.3 Electro Magnetic Pulse (MN)
7.2.2.4 Explosives (MN)
7.2.2.5 Projectiles (MN)
7.2.2.6 Directed Energy (MN)
7.2.2.7 Electro-Magnetic Spectrum (MN)
7.2.2.8 Natural Hazards (MN)
7.3 **Research and Development**
7.3.1 Basic Research
7.3.2 Applied Research
7.3.3 Advanced Technology Development

Concept of Operation

- The VULTURE concept is intended to:
  - Provide continuous persistent sensor coverage over Oil Platform and surrounding waters
  - Provide early warning to Oil Platform of possible threats
  - Deal with Threats via direct neutralization or indirect action (alerting forces capable of neutralizing the threat)
  - Operate within three basic scenarios that include small, atypical vehicles whose primary means of attack fall under the suicide bomber realm.
  - Leave the larger, conventional, technologically advanced threats, such as nuclear submarines or tactical strike aircraft to be dealt with via the legacy Order of Battle, as engaging them is not an intended VULTURE mission.

OV-1



Concept of Operation

- Overall, the VULTURE design should meet the following high level needs:
  - Provide situational awareness around sea-based assets at distances sufficient to neutralize detected threats.
  - Perform ISR alert function and will, when appropriate, monitor and engage threats.
  - Operate and manage system assets autonomously, including autonomous refueling/recharging to minimize human supervision/control/support.
  - Process data autonomously to provide a knowledge base for the operational forces and commanders so that they can make informed decisions.
  - Deploy non-lethal and lethal weapons under human command and control.

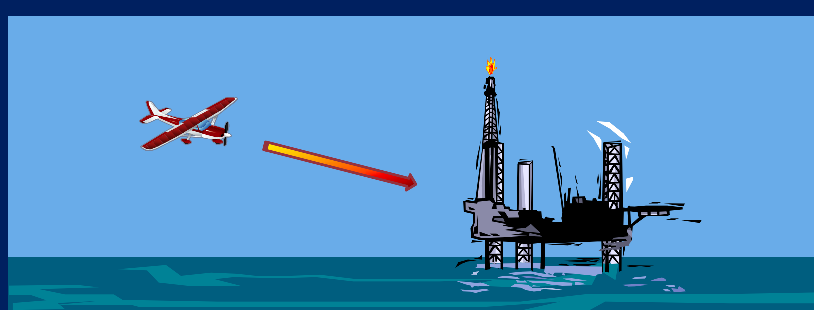
Missions Cont'd

- Missions derived from Universal Naval Task List

The mission of the VULTURE system is to provide defense of sea-based oil platforms from attack by surface, subsurface, and aircraft threats and to protect United States citizens and allies from injury.

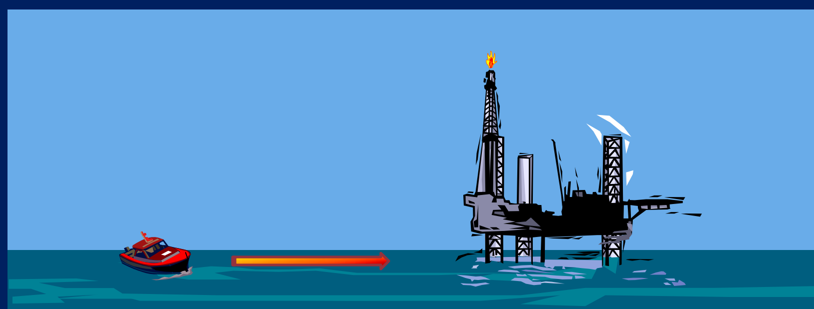
Scenario 1

- Under this scenario, a small propeller driven aircraft is employed by threat forces, and maneuvered on a collision course with the Oil Platform. The aircraft chosen will most likely be one of similar characteristics of those utilized by the local indigenous civilian populace, making it difficult to determine intent. This threat could take place during day or night, but would be confined to fair weather (Visual Meteorological Conditions).



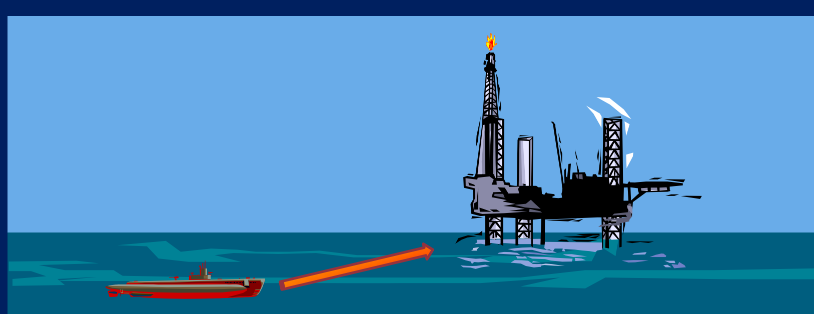
Scenario 2

- Under this scenario, a small surface vessel or personal water craft (PWC) is maneuvered on a collision course with the Oil Platform to either detonate on impact, or permit personnel to embark the Oil Platform. Once again, this vessel would be similar to local fishing, recreational vehicles. This threat could be during day or night, but would most likely occur during calmer sea states.

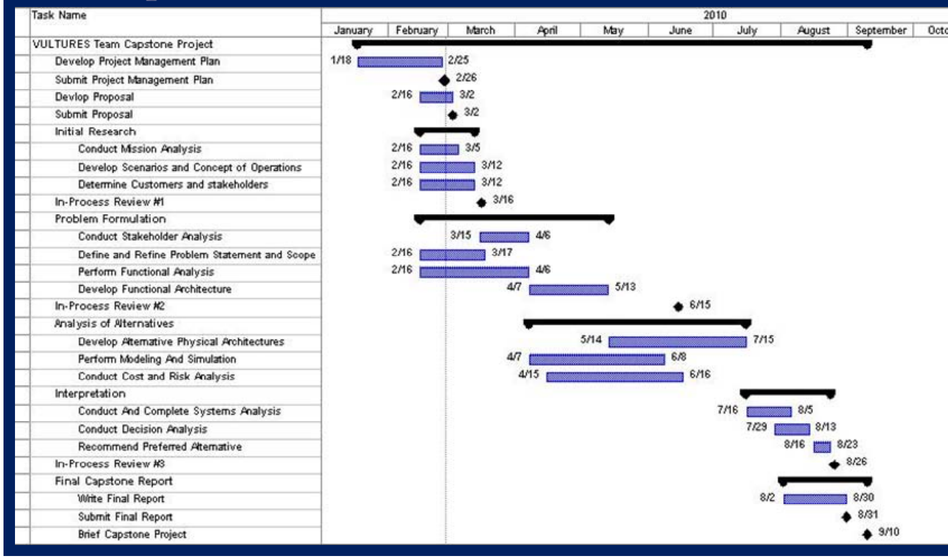


Scenario 3

- Under this scenario, a small submersible/semi-submersible vehicle would be employed and maneuvered to either collide and detonate at the Oil Platform, or permit personnel to embark the Oil Platform. Current threat platforms are similar to those employed by Narco-Terrorists in the smuggling of narcotics in the Caribbean/Central America regions. This threat could be day or night, but most likely during calm sea states.



Project Plan



What's Next

- Finish identifying stakeholders & customers
- Begin problem formulation activities
  - Refine stakeholder analysis
  - Perform functional analyses
  - Build architecture

Summary

- Delivered proposal & PMP
- Completed mission analysis
- Defined operational environment
- Conducted research into problem statement
- Developed CONOPS
- Defining stakeholder & customers

Questions & Feedback

Back-up Slides

References

- SIO810 March 11, 2010 Program Management Plan
- SIO810 March 18, 2010 Project Proposal
- http://www.whisprwave.com/oil-platform-security.htm
- http://www.sarad.de/Dateien/Paschoa__-_Accidents_and_terror_attacks_against_offshore_oil_rigs.ppt
- http://www.bloomberg.com/apps/news?pid=newsarchive&sid=amNKugHA6mjI&refer=home-redirectoldpage
- http://www.necc.navy.mil/
- Market Survey for NAVAIR PMA 263 Sea Scout Program January 2007.

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Operational Environment

- **Operational Environment**
  - Operate in day - Utilize system during high ambient light conditions.
  - Operate at night - Utilize system during low ambient light conditions.
  - Operate all weather - Utilize system during the weather conditions described in environmental conditions slide.
  - Operate on/over land - Sustain mission capability regardless of terrain.
  - Operate in Blue Water - Sustain mission capability in open ocean.
  - Operate in Brown Water - Sustain mission capability regardless of environmental obstacles in the littoral area.
  - Operate from Multiple Host Platforms - Deploy/monitor from multiple, air, sea, and land legacy platforms.

Environmental Conditions

- **Maritime/Aviation conditions:**
  - **Sea state: <3**
  - **Water Temperature: 32 F – 105 F**
  - **Clouds/Precipitation (limited visibility)**
    - **To limits of sensors**
  - **Winds: <45 knots**
  - **Air Temperature: -50 F – 140 F**
  - **Icing: Operations permitted into forecast or known trace or light icing conditions**

APPENDIX G IPR 2 SLIDES

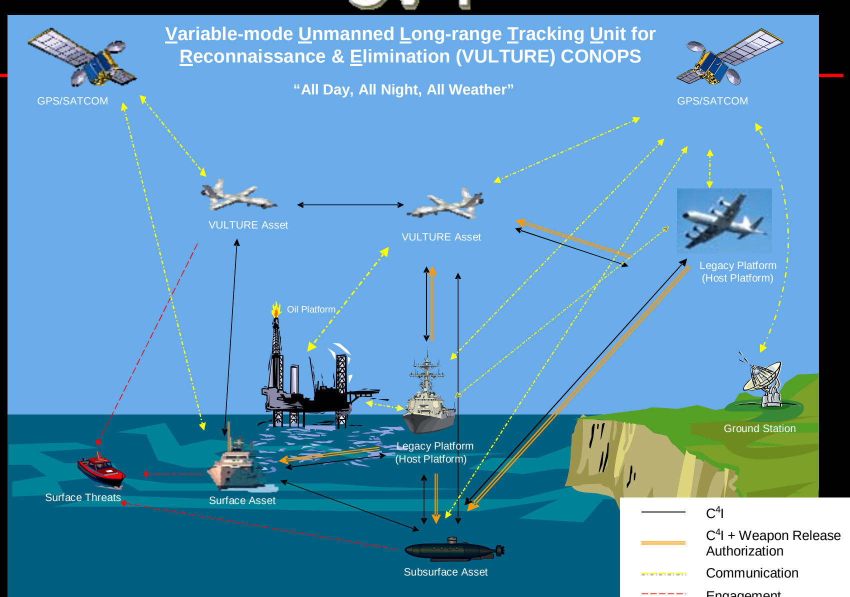
IPR #2

Agenda

- Project Proposal Review/Re-scope
- Environmental Conditions
- Primary Stakeholders
- Requirements
- Developing a Traceable Top Level System Design Approach
- Functions
- Components
- Alternatives
- Project Schedule
- Questions & Feedback

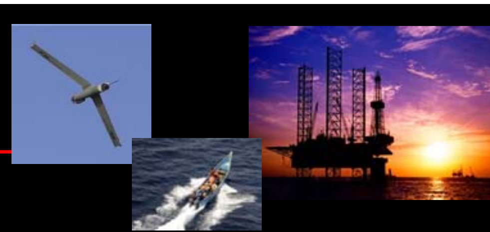
2

OV-1



3

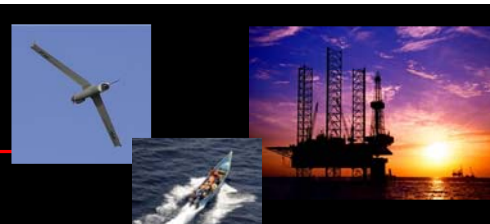
Project Focus



- Global terrorist threats targeted at oil production and distribution facilities are a clear and present danger. As evident in the current disaster in the Gulf of Mexico caused by accident, a deliberate attack by a determined enemy can cause significant environmental and economic damage to the United States or its allies and the global economy.
- Therefore, an urgent need is required for the capability to provide continuous, all-weather, autonomous protection of domestic and foreign oil platforms to ensure against an attack which could cause similar calamity.

4

Project Focus Cont.



- Problem Statement: Due to the limitations of on-platform ISR capability, there is a limited early positive ID capability of possible threats which does not allow for timely and efficient protection of the Oil Platform prior to a hostile event.
- Capability Need Statement: There is a need to maximize the surveillance and positive identification capabilities regarding possible surface threats while also minimizing the manpower footprint and maximizing threat neutralization efficiency.

5

Project Proposal Review/Re-scope

- Project Phases
  - Initial Research – conducting mission analysis, developing scenarios, concept of operations, and identifying the customers and stakeholders of the system
  - Problem Formulation – Stakeholder interviews, requirements generation, functional architecture, and component development.
  - Analysis of Alternatives – Developing alternatives to compare against cost, performance and risk.
  - Synthesis – Simulation and recommendation
- Status of Project Phases
  - Initial Research and Preliminary Problem Formulation (IPR1)
  - Rescoped Proposal, Continued Problem Formulation, and began Analysis of Alternatives (IPR2)
  - Synthesis (still to complete)
- The project was rescoped to focus on Surface Threats only (eliminated subsurface and airborne).

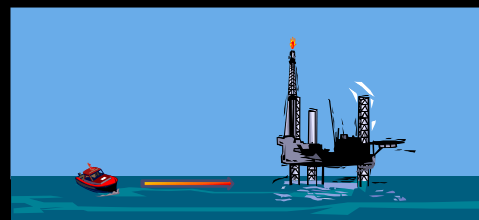
6

Revised Research Questions

- What functions, subsystems, and components will be required for the VULTURE system to achieve the ability to detect, engage and neutralize surface threats in a time-critical environment and allow for successful defense of an Oil Platform?
- What Measures of Effectiveness (MOE) should be used to determine the value of the VULTURE system to perform its intended mission?
- What Measures of Suitability (MOS) should be established to ensure successful operation in intended environment?
- How do we judge success? (Number of successful attacks vice thwarted attacks / total attacks, lack of surface threats to be engaged, boats turned away hourly/daily/monthly, etc)

7

Threat Details



- Small watercraft < 50 ft
- Max speed < 40 knots
- Max personnel < 25

- Most Likely Threat
  - Small innocuous looking boat laden with explosives and suicide crew such as that employed against USS Cole
- Most Dangerous Threat
  - Fast moving, low signature vessel capable of carrying a large amount of explosive materials that could result in irreparable damage if detonated in close proximity to the Oil Platform

8

Environmental Conditions

- Maritime/Aviation conditions:
  - Day, night, or low-visibility (rain/fog)
  - Sea state: < 4
  - Clouds/Precipitation (limited visibility)
    - To limits of sensors
  - Winds: < 35 knots
  - Ambient Air Temperature: 0 – 120 F
  - Icing: Operations permitted into forecast or known trace or light icing conditions
  - Day or Night
  - Air, Sea or Land based

9

Friendly Forces

- Multiple Oil Platforms
- Available Maritime / Aviation Assets
- Distance from shore
  - > 5 Nm
- Response Force(s)
  - CONUS
    - Coast Guard
  - OCONUS
    - NECC

10

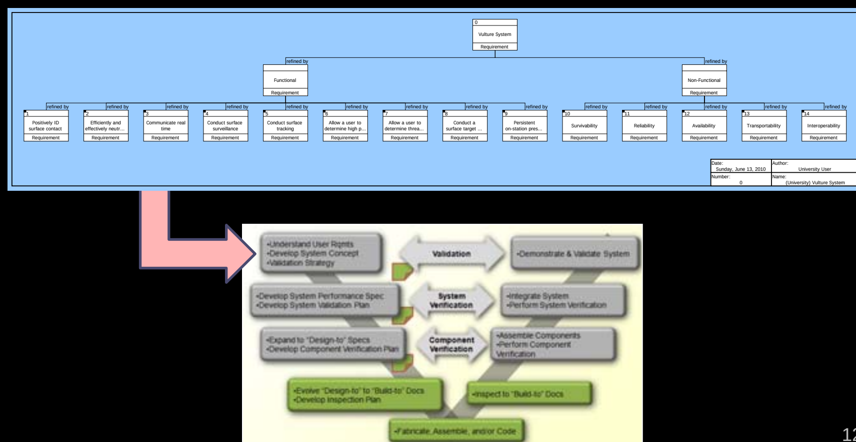
Primary Stakeholders

- Navy Expeditionary Combat Command (NECC)
  - CDR Gary Lauck, N9 (S&T) COMNECC
  - Charlie Sullivan, Maritime Expeditionary Group 2 (MEG-2)
  - CDR John Anderson, N3 (Man, Train, & Equip)
  - This is the command currently supplying OPLAT defense in the Arabian gulf
  - http://www.necc.navy.mil/
- PMA-263
  - LT Col John Neville, IPT Lead, STUAS
  - STUAS – Small Tactical Unmanned Air Systems
  - Leverage proven UAS technology (STUAS) that is currently utilized for similar missions
  - http://www.navair.navy.mil/pma263/

11

Requirements Hierarchy

- Decomposed user requirements in CORE 6.0



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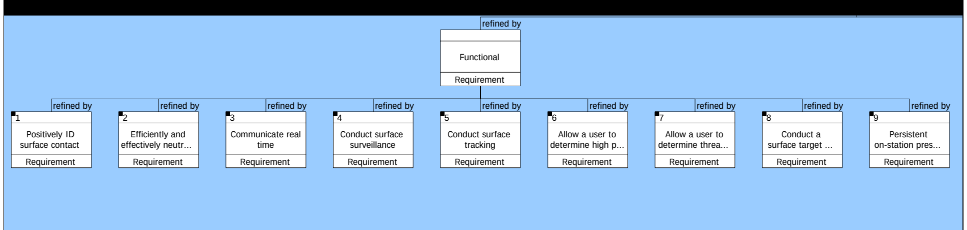
Requirements Hierarchy

- Decomposed user requirements in CORE 6.0



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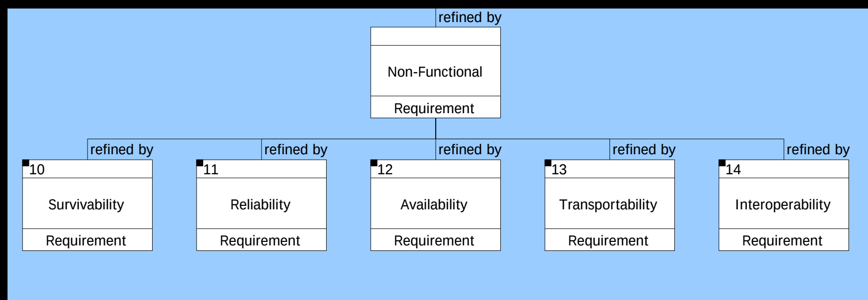
Requirements Hierarchy

- Decomposed user requirements in CORE 6.0



14

MOEs/MOSs

- Positive ID (% positive ID)
- Minimize threat response time (Minutes)
- Minimize manpower footprint (Man hours saved)
- Minimize threat deterrence (Hours uninterrupted oil operations)
- Transmit track location (Mb/sec)
- Transmit track speed (Mb/sec)
- Transmit track ID (Mb/sec)
- Long range target detection (% detection)
- Short range target detection (% detection)
- Track multiple targets (# of targets tracked)
- Launch weapon on/near target (% targets destroyed/deterred)
- Endurance (Hours over station)
- Launch/Recovery time (Minutes)
- Survivable (Probability of kill)
- Reliable (Mean time between failure)
- Available (Mean time to repair)
- Physical size (sq-ft)
- Weight (lbs)
- Interoperable (% successful)

15

Developing a Traceable Top Level System Design Approach

- Customer Survey
  - Extracts relative importance of top level requirements from customer
- Pairwise Comparison
  - Normalizes customer rankings to determine most important requirements
- Quality Function Deployment (QFD) 1
  - Aligns system requirements with system design characteristics
- QFD 2
  - Aligns system design characteristics with system level functions
- QFD 3
  - Aligns system level functions with physical subsystems

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Customer Survey

Conduct positive visual ID of surface contact	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Efficiently and Effectively Neutralize Known Surface Threats.
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Communicate Real Time
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Conduct Surface Surviellance
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Conduct Surface Tracking
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Allow a user to Determine High Priority Targets
Conduct positive visual ID of surface contact	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Allow a user to Determine Threat Neutralization Method
Conduct positive visual ID of surface contact	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Conduct a Surface Target Engagement
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	9	Persistent On-Station Presence
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Survivability
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Reliable
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Available
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Transportable
Conduct positive visual ID of surface contact	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Interoperability

Relative ranking of top level system requirements by PMA-263 Small Tactical UAS program

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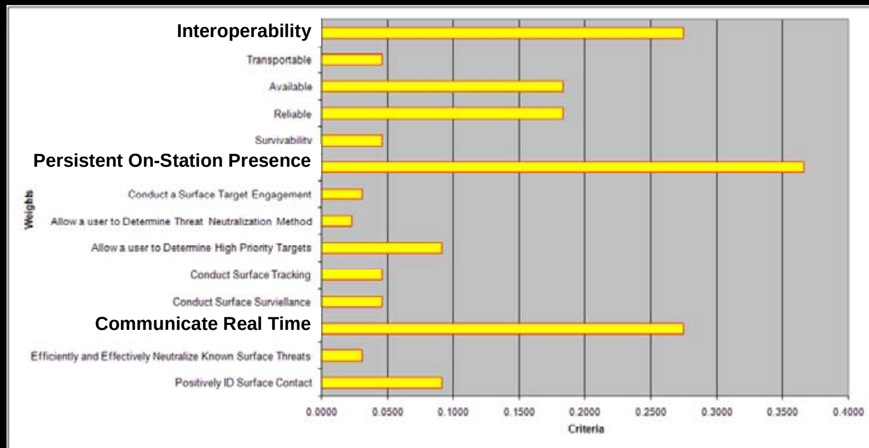
Pairwise Comparison



Customer inputs normalized and ranked to determine relative importance

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QFD 1

Design Characteristics

Customer Requirement (What	Normalized	1 Positive ID	2 Minimize threat response time	3 Minimize Manpower Footprint	4 Maximize threat deterrence	5 Transmit Track Location	6 Transmit Track Speed	7 Transmit Track ID	8 Long Range Target Detection	9 Short Range Target Detection	10 Track Multiple Targets	11 Launch Weapon on/near Target	12 Endurance	13 Launch/Recovery Time	14 Survivable	15 Reliable	16 Available	17 Physical size	18 Weight	19 Interoperable
		% Pos ID	Minutes	Man Hours Saved	Hrs uninterrupted ol ops	Mb/sec	Mb/sec	MB/sec	%	%	#	%	Hours	Min	Probability of Kill	MTBF	MTTR	sq.ft.	lbs	%
Positively ID Surface Contact	0.053	9	3		3			9	1	1	1	3								
Efficiently and Effectively Neutralize K	0.018	3	1		9	9	9	3			1	9	1	1		1	1			1
Communicate Real Time	0.159	3	3	3		9	9	9	3	3	1									3
Conduct Surface Surviellance	0.026	1		3	1	1	1	1	9	9	1		3		1	1	1			
Conduct Surface Tracking	0.026	1		1	1	9	9	9			3	3				1	1			
Allow a user to Determine High Prior	0.053	3	3	1		9	9	9	1	3	3					1	1			1
Allow a user to Determine Threat Ne	0.013	3	3	1	1	3	3	3				9	1			1	1			
Conduct a Surface Target Engageme	0.018	3	9	1	9	9	9	9				9	1			1	1			
Persistent on-station presence	0.211		9	9	3				1	1	1		9	3	3	3	3			
Survivability	0.026	1										1	1		9					
Reliability	0.106		9	3	3							1	3		1	9	3			3
Availability	0.106		1	3	3							1	3	3	1	3	9			3
Transportability	0.026																3	9	9	1
Interoperability	0.159	3	3	3	1								1			1	1			9
Check Sum																				
Goal Value																				
Threshold Value																				

Relationship of System Design Characteristics to Top Level System Requirements

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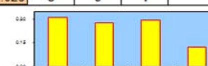
QFD 2

Design Characteristics	Weights	1 Maintain On-Station Presence	2 Conduct Surface Surveillance	3 Perform Command & Control (C2)	4 Neutralize Surface Threat
Positive ID	0.050	3	9	1	3
Minimize threat response time	0.123	9	3	3	1
Minimize Manpower Footprint	0.102	3	1		3
Maximize threat deterrence	0.054	3	3	3	9
Transmit Track Location	0.070		3	9	
Transmit Track Speed	0.070		3	9	
Transmit Track ID	0.080		3	9	
Long Range Target Detection	0.028	3	9	1	

(Full list not shown)



Relationship of Top Level Functions to System Design Characteristics

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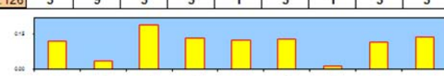
QFD 3

Functions	Weights	1 Data Processing SS	2 Weapons SS	3 Surveillance SS	4 C2 (ISR)	5 Network	6 Propulsion SS	7 Launch/Recovery SS	8 Communications SS	9 Air Vehicle SS
Maintain On-Station Presence	0.309			9	3	3	9		1	9
Conduct Surface Surveillance	0.274	9		9	1	1	3	1	1	1
Perform Command & Control (C2)	0.291	3		1	9	9			9	3
Neutralize Surface Threat	0.126	3	9	3	3	1	3	1	3	3



Relationship of Physical Subsystems to Top Level Functions

Concentrate resources on the most critical subsystems…but don't ignore the rest of them

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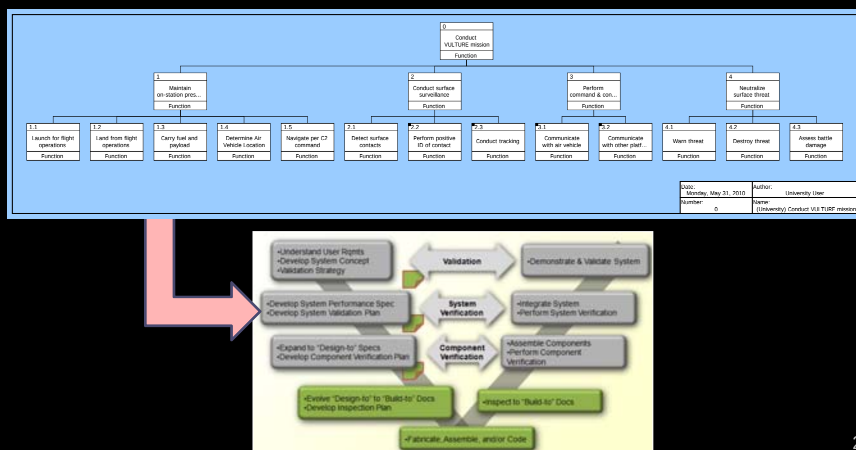
Functional Architecture

- Developed functions from user requirements



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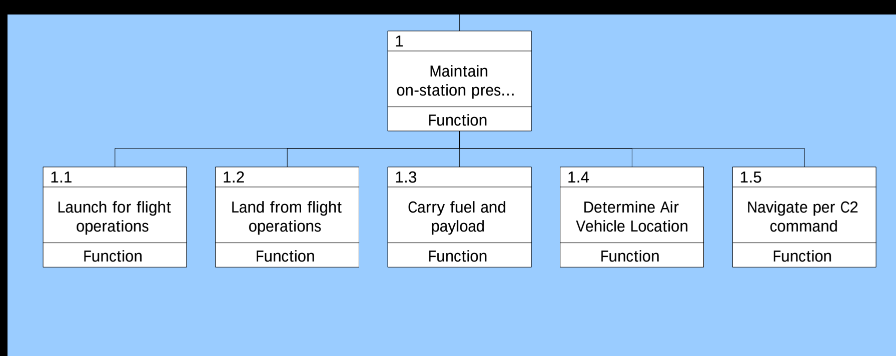
Functional Architecture

- Developed functions from user requirements



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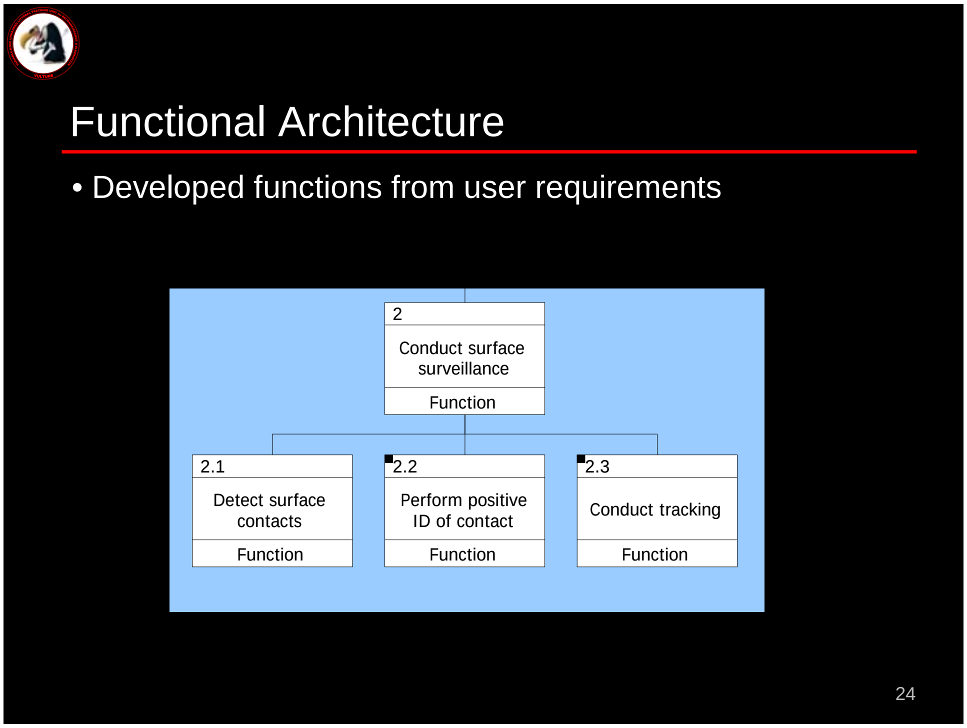
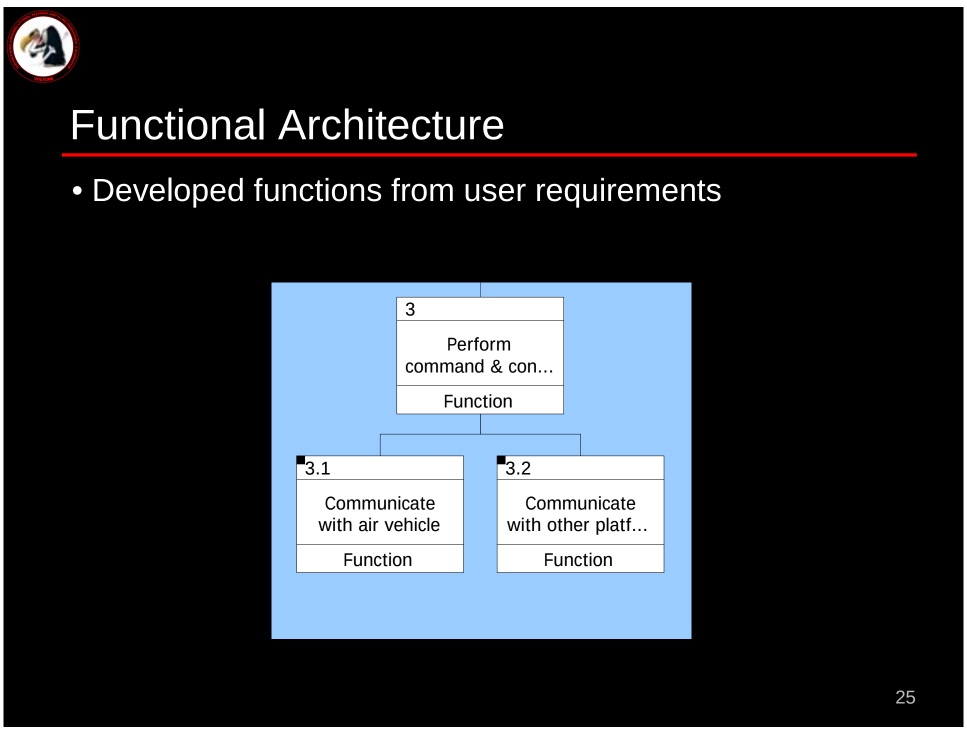
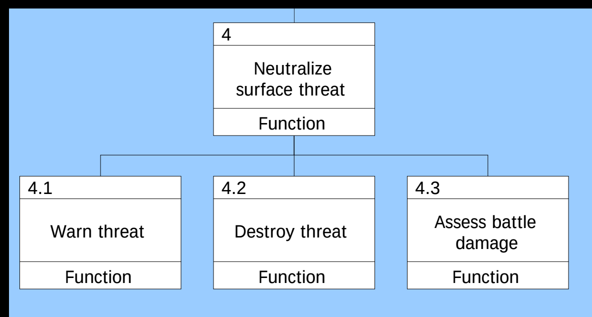

Functional Architecture
• Developed functions from user requirements
2
Conduct surface surveillance
Function
2.1
Detect surface contacts
Function
2.2
Perform positive ID of contact
Function
2.3
Conduct tracking
Function
24


Functional Architecture
• Developed functions from user requirements
3
Perform command & con...
Function
3.1
Communicate with air vehicle
Function
3.2
Communicate with other platf...
Function
25

Functional Architecture

- Developed functions from user requirements



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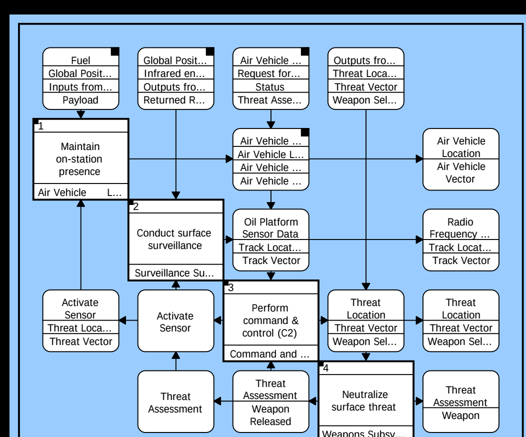
Functional Architecture Cont'd

- N^2 diagram showing interrelationships between functions



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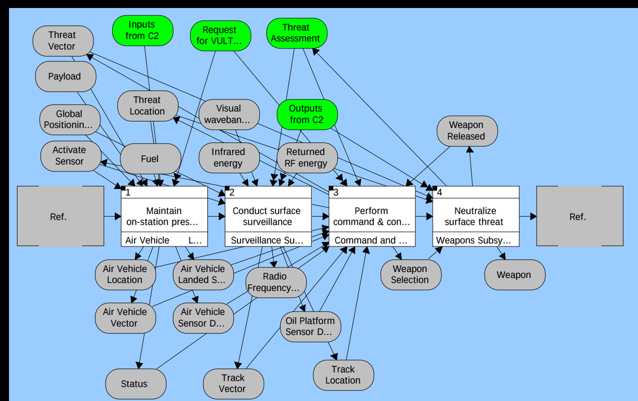
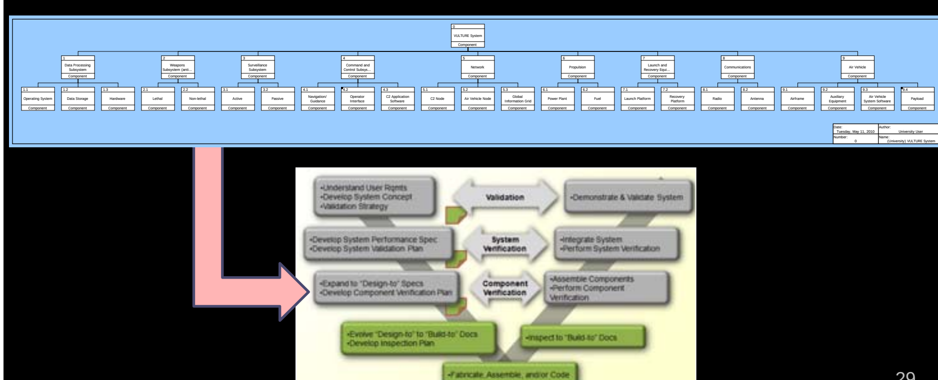
Functional Architecture Cont'd

- Enhanced Functional Flow Block Diagram



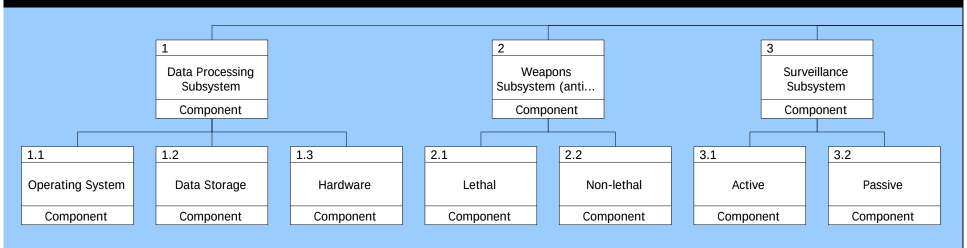
Components Hierarchy

- Determined components from user requirements



Components Hierarchy

- Determined components from user requirements



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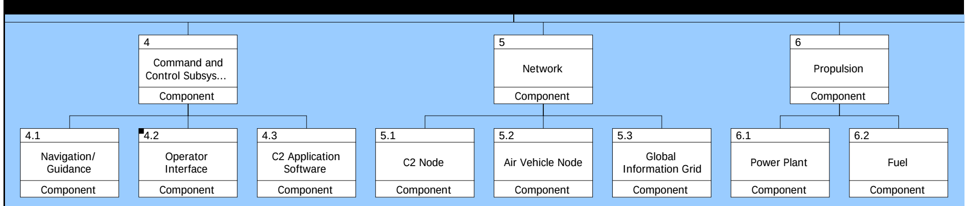
Components Hierarchy

- Determined components from user requirements



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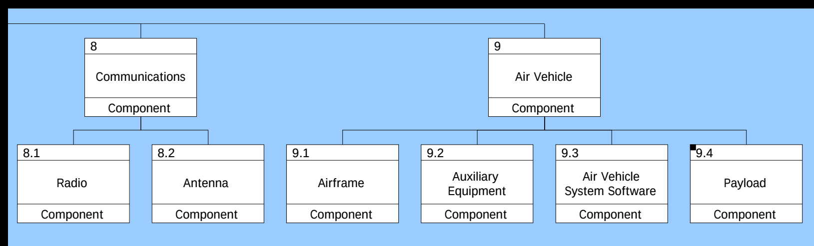
Components Hierarchy

- Determined components from user requirements



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Concept Alternatives

Form Components	Sub-Component	Concept Alternatives			
Data Processing Subsystem					
	Operating System	Windows	Unix	Solaris	
	Data Storage	Hard Drive	Flash Drive		
	Hardware	COTS	Legacy		
Weapons Subsystem (Anti-Surface)					
	Lethal	rockets	guns	missiles	
	non-lethal	visual	audio	electromagnetic	
Surveillance Subsystem					
	Active	RADAR			
	Passive	IR	EO	ESM	
Command and Control Subsystem (ISR)					
	Navigation/Guidance	INS	GPS	EGI	
	Operator Interface	Permanent	Portable		
Network					
	C2 Node	Link-11	Link-16		
	Air Vehicle Node	Link-11	Link-16		
Propulsion					
	Power Plant	jet	propeller	air	solar
	Fuel	JP-5	Battery		
Launch/Recovery Equipment					
	launch platform	ship	land	oil platform	Air Platform
	recovery platform	ship	land	oil platform	
Communication Subsystem					
	Radio	HF	UHF	VHF	
Air Vehicle					
	Airframe	Rotary Wing	Fixed Wing	Lighter than air	
	Payload	Sensors	Weapons		

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Analysis of Alternatives Plan

- Rate Concept Alternatives relative to each other based on MOE/MOS metrics
  - Based on research, known performance, or technical perception
- A Morphological Matrix will be developed to determine the best combinations of alternatives
- These combinations will then be rated for integration difficulty (risk) and cost as an independent variable (CAIV)
- A Cost versus Performance plot will fall out that should identify the most “bang for buck” combination of alternatives
- Simulation of air vehicle type related to persistent on-station presence.

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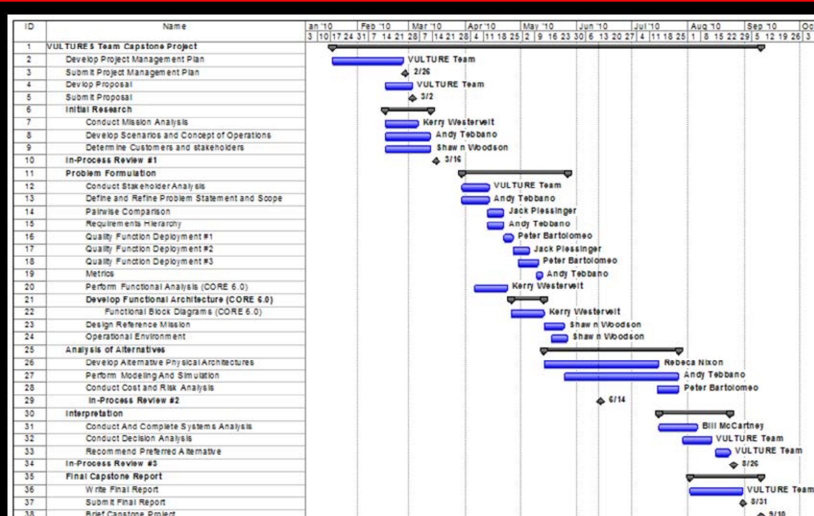
Project Schedule



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Work Completed to Date

- Refined Scope of project
- Solicited input from stakeholders
- Developed Requirements, MOEs/MOSs, Functions and Components
- Utilized QFD tools to determine most important elements
  - Requirements
  - Functions
  - Components
- Began Analysis of Alternatives

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Still to Come

- Continue Analysis of Alternatives
  - Obtainable (technical maturity)?
- Cost Analysis
  - CAIV
  - Life Cycle Cost
- Risk Assessment
- Final Simulation
- Report

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Questions & Feedback

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Back-up Slides

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Concept of Operation

- Overall, the VULTURE design should meet the following high level needs:
  - Provide situational awareness around sea-based assets at distances sufficient to neutralize detected surface threats.
  - Perform ISR alert function and will, when appropriate, monitor and engage threats.
  - Process data to provide a knowledge base for the operational forces and commanders so that they can make informed decisions.
  - Deploy non-lethal and lethal weapons under human command and control.

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